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AN UNUSUAL SPECTROSCOPIC BINARY (27 CANIS MAJORIS)

By OTTO STRUVE

ABSTRACT

The *velocity curve* of the spectroscopic multiple star 27 Canis Majoris was derived from 48 spectrograms obtained at the Yerkes Observatory and from 10 earlier Lick observations. The lines of *two components*, A and C, are visible in the spectrum. *Variable bright hydrogen lines* are present. The spectral type of A is *B5ne* while that of C is *B8*.

Component A has a *shorter period* of 121 days, indicating the presence of an invisible component B. The semi-amplitude of this variation in velocity is 25 km/sec., and the orbit is circular.

C is probably also double: an invisible companion D seems to revolve around it in a period of something like 8 days with K roughly equal to 50 km/sec.

The system C+D revolves around A+B in a *period of 3.2 years*. In this orbit $K=110.5$ km/sec. and $e=0.33$. *The total minimum mass of the quadruple system is 950 times that of the Sun.* The mass ratio of C+D to A+B is approximately one, but the ratios of A to B and of C to D are not known. On the average, each of the four components has a mass of at least 238 times that of the Sun.

These masses are larger than any that have hitherto been found. An inspection of the observational material shows that the only orbital element that can seriously affect the mass is the eccentricity. But even under the most liberal assumptions concerning e the masses remain unusually large.

The possibility is discussed that the observed shifts of the spectral lines are not due to Doppler effect, or that the adopted period is in error. Neither assumption is satisfactory.

It is a well-known fact that the masses of spectroscopic binaries and of eclipsing variables show little dispersion if stars of only one spectral class are considered. The largest masses occur among stars of spectral type O and of the earliest subdivisions of type B.[1] Spectro-

[1] The latest list of spectroscopic systems of large mass is that of J. A. Pearce, *Publications of the Dominion Astrophysical Observatory, Victoria*, **3**, 298, 1926.

scopic systems with minimum masses of more than thirty times that of the Sun are unusual, and only one binary (B.D.$+6°1309$)[1] is known that has a minimum mass of one hundred and fifty times that of the Sun. The present paper deals with another star of unusually large mass. Only preliminary results can be given at this time, but they lead to somewhat unusual consequences and are therefore published without waiting for more observations.

The position of 27 Canis Majoris, or Boss 1872, for 1900, is α $7^h10^m.2$, $\delta -26°10'$, and it is situated about a half-degree to the north of the bright-line B star ω Canis Majoris. Its number in the *Henry Draper Catalogue* is 56014, and its visual and photographic magnitudes are 4.66 and 4.54, respectively. The spectral type is given as *B5p*. The lines of helium are rather wide and diffuse. Magnesium λ 4481 is faint and not suitable for accurate measurement. The iron line λ 4549 is faint but measurable on some of the better plates. The hydrogen absorption lines are sharper and narrower than is usually the case for stars of this type. On several plates $H\beta$ was thought to be accompanied by a faint emission line. The velocities derived from the hydrogen absorption lines agree well with those of the helium lines, and I have usually measured $H\delta$, $H\gamma$, and $H\beta$, in addition to *He* 4026, *He* 4388, *He* 4472, *Fe* 4549, and in a few cases also *Mg* 4481, *Ca* 3933, *Ca* 3968, and $H\epsilon$ 3970.

The bright lines of hydrogen were first discovered by Miss A. J. Cannon[2] at the Harvard College Observatory. In April, 1895, the bright line at $H\beta$ was found to be stronger than the same line in ω Canis Majoris. $H\gamma$ was bright at the same time. Bright $H\beta$ was observed again in March, 1890, and in October, 1897. On several other dates all the hydrogen lines were dark. The star was observed by P. W. Merrill[3] on December 2 and 11, 1912. $H\alpha$ showed a weak, bright line but $H\beta$ and $H\alpha$ were visible only in absorption. Merrill remarks: "The bright $H\alpha$ does not partake of the high positive velocity displacement of the absorption lines."

Before I was acquainted with the earlier work of Miss Cannon

[1] J. S. Plaskett, *ibid.*, **2**, 147, 1922.

[2] *Annals of Harvard College Observatory*, **28**, 184, remark 101, 1901; *Publications of the Astronomical and Astrophysical Society of America*, **1**, 216, 1904.

[3] *Lick Observatory Bulletin*, **7**, 170, 1913.

and of Merrill I suspected a bright line at $H\beta$ on some of the more recent Yerkes plates. This bright component is very faint, and at no time even approximates that of ω Canis Majoris. The bright line at $H\beta$ was strongest in April, 1927. All other lines remained dark. Taking into consideration the Harvard observations of 1895, this would suggest either an irregular sort of variation or one of long period. The observations on the bright lines are not sufficient to find any relation between their variability and the spectroscopic periods discussed later in this paper.

The strongest lines in the spectrum, aside from those of hydrogen, are due to helium. No lines of *Si*+++ or *O*+ are visible with certainty. *Si*+4128 and *Si*+4131 are very faint, while *He* 4121 is well visible. *Mg*+4481 is much fainter than *He* 4472. *Ca*+3933 and *Ca*+3968 are faint and fairly narrow. They share the displacements of the other lines and are not due to interstellar calcium. However, on one very good plate where the stellar calcium line has a large negative displacement there was measured a very faint line that may be identical with the detached line. The velocity was +48.5 km/sec. The component of the solar motion in the direction of 27 Canis Majoris is about 19.5 km/sec. This single measurement does not carry much weight. The spectral type appears to be intermediate between B3ne and B5ne.

It might be mentioned that 27 Canis Majoris was suspected to be a variable star by J. E. Gore[1] and that more recently P. Guthnick[2] has called attention to the fact that the residuals in the *Revised Harvard Photometry* are "nicht unbeträchtlich."

The variable radial velocity of 27 Canis Majoris was first suspected by S. Albrecht[3] at the Lick Observatory and independently suspected and confirmed by G. F. Paddock[3] at the Chile station of the Lick Observatory. Dr. J. H. Moore has very kindly placed at my disposal the measures of ten plates of this star made at the Lick Observatory. Eight of these had previously been published.[3] The velocities from the Lick Observatory cover more than two years (1908, 1909, and 1910) and show a range from +88 to +118 km/sec.

[1] *Proceedings, Royal Irish Academy*, Ser. 2, **4**, 340, 1884.

[2] *Astronomische Nachrichten*, **191**, 179, 1912.

[3] *Lick Observatory Bulletin*, **6**, 4, 1909.

At the Yerkes Observatory three early plates were available; two of these, taken in February, 1907, gave almost identical velocities of +45 km/sec. A third plate, in October, 1916, gave +22 km/sec. The large difference between the Yerkes velocities and those from the Lick Observatory suggested that the star would be interesting. Observations with the Bruce spectrograph were started on November 19, 1925, and continued until April 7, 1927. A dispersion of one prism was used throughout this work. The observations of 1925–1926 showed from the beginning a variable radial velocity, and a period of three to four months was clearly indicated. But the second observed maximum did not reach the height of the first one; and the second minimum was far below the first minimum. Observations were then discontinued during the summer season, on account of the right ascension of 7^h10^m, and they were resumed again in October, 1926. The observations of this season also showed a periodicity of about one hundred and twenty days, but all of them were from about 25 to 200 km/sec. lower than the observations of 1925–1926. This shows definitely the existence of a long period with a range in velocity from +118 to −85 km/sec.

THE LONG PERIOD

The three early Yerkes plates together with the Lick Observatory velocities fix the long period at about 3.2 years. We have two velocities of about +45 km/sec. in February, 1907, and several around +90 km/sec. in November, 1909. A still greater velocity of more than +100 km/sec. was reached in December, 1910. There can be only two alternatives: either the two first velocities of +45 km/sec. lie on the descending branch of the velocity curve, while those of November, 1909, fall on the ascending branch; or else all of them fall on the ascending branch. The first alternative fits in very well with the observations of 1925–1927 and leads to a period of 3.2 years. All observations are satisfactorily explained on this assumption. The second alternative combined with the observations of 1925–1927 would lead to a period of about eight years. This is ruled out by the observation of October, 1916. A period of eight years would place this date not far from maximum velocity, which should be about +118 km/sec. In reality we have from two inde-

pendent measures of the same plate +22.5 and +21.1 km/sec. The quality of the plate is fairly good, and it can be taken as a sufficient confirmation of the period of 3.2 years.

The uncertainty introduced by the shorter period of four months is of no consequence in this connection since its amplitude is small compared to that of the long period.

It will be noticed that our period of 3.2 years is also in good agreement with the high-positive velocity displacement observed by Merrill[1] in December, 1912. Maximum velocity occurred about the middle of 1909 and again during the latter half of 1912.

On account of the southern declination of 27 Canis Majoris, it is observed here almost invariably near the meridian. Under such conditions the possibility of a period approximately equal to one day must be kept in view. Special continued observations were made on several nights in order to settle this point. They show that a period of about one day is hardly possible, and this seems to be confirmed by the Chile observations of the Lick Observatory. The improbability of a period of almost exactly one day is also demonstrated by the curves in my paper on spectroscopic binaries.[2] It was shown there that no real double stars of spectral type B are known the period of which is shorter than 1.3 days.

However, I feel that although in all probability the period is not one day, additional observations in different hour-angles would be very desirable. Unfortunately, we are unable to carry them out at this Observatory.

After a number of trials the most probable value of the period was found to be 1165 days. Figure 1 shows the corresponding velocity curve, without respect to the variation in the period of four months.

THE ORBIT

The orbital elements were derived from this curve by graphical methods. In view of the uncertainty of the curve I have not attempted a least-squares solution. However, an inspection of the observations shows that the elements cannot be much in error. The minimum of the velocity curve has not been observed. But the shape

[1] *Ibid.*, **7**, 170, 1913.

[2] *Monthly Notices of the Royal Astronomical Society*, **86**, 70, 1925.

of the observed portions of the curve suggests that minimum velocity will not be much lower than about -100 km/sec. The ellipticity of the orbit may be slightly larger than would result from the curve. But it is very unlikely that it should exceed a value of 0.5. Such a change would very slightly alter the results concerning the mass and the size of $(a \sin i)$, since an increase in e will be largely compensated by a similar increase in K.

Thus far we have dealt with the measures derived from only one component of this system, and have found that it shows two oscilla-

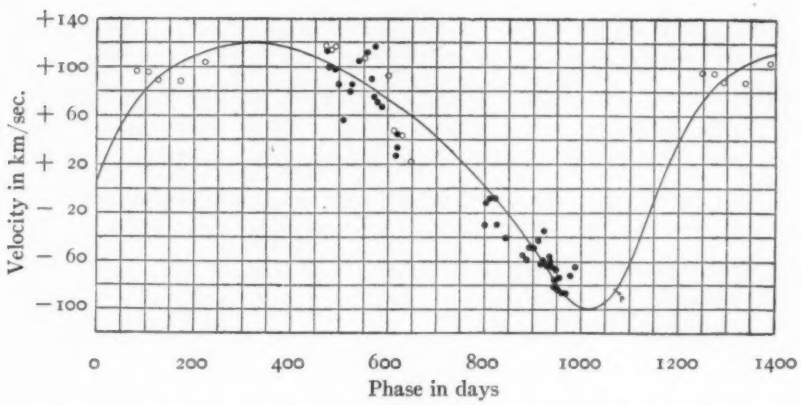

FIG. 1.—Velocity curve of the spectroscopic multiple star 27 Canis Majoris. The period is 3.2 years or 1165 days. The phases are counted from J.D. 2424000. The old observations of 1907–1916 are indicated by open circles.

tions. Accordingly, we assume that we are dealing with a comparatively close system, A and B, having a period of about four months and a distant companion, C, revolving around A+B in 3.2 years. The lines of C are also visible in the spectrum of this star, and they have been measured on many plates. They are weaker than the lines of A (B is not visible in the spectrum), and indicate a slightly more advanced spectral type. The magnesium lines (at λ 4481) of A and C are almost alike, A being a trace stronger. On the other hand, the helium lines of C are much fainter than those of A. Accordingly, the spectral type of C seems to be about B8, while that of A is B5ne or B3ne. The difference of magnitude between A+B and C is small, possibly about $0^{m}.3$.

TABLE I

RADIAL VELOCITIES OF 27 CANIS MAJORIS

Date G.C.T.	Observer	Qual.	Vel. I	Vel. II	Phase
1907 Feb. 16.14.....	Fox, S	f	+ 47.6	.....	614
1907 Feb. 22.14.....	F, S	f	+ 43.0	.....	620
1908 Nov. 10.53.....	Lick	.....	+ 98.6	.....	81
1908 Dec. 5.47.....	Lick	.....	+ 96.2	.....	107
1908 Dec. 24.29.....	Lick	.....	+ 89.2	.....	126
1909 Feb. 8.16.....	Lick	.....	+ 88.0	.....	172
1909 Mar. 31.18.....	Lick	.....	+104.3	.....	223
1909 Dec. 6.20.....	Lick	.....	+118.0	.....	473
1909 Dec. 20.28.....	Lick	.....	+116.0	.....	487
1909 Dec. 22.27.....	Lick	.....	+116.6	.....	489
1910 Feb. 24.12.....	Lick	.....	+108.2	.....	553
1910 Apr. 13.04.....	Lick	.....	+ 93.0	.....	601
1916 Oct. 16.47.....	B, S	f	+ 21.8	.....	649
1925 Nov. 19.40.....	σ, S	g	+116.8	− 65.8	474
1925 Nov 23.39.....	σ, S	g	+100.0	− 31.8	478
1925 Dec. 7.42.....	σ, S	f	+ 98.2	.....	492
1925 Dec. 13.38.....	σ, S	g	+ 85.0	− 93.1	498
1925 Dec. 24.29.....	σ,B,S	p	+ 56.0	.....	509
1926 Jan. 7.23.....	σ, S	g	+ 80.0	− 76.6	524
1926 Jan. 10.23.....	B, S	g	+ 85.9	.....	526
1926 Jan.. 24.27.....	B,σ,S	g	+105.2	− 62.8	540
1926 Feb. 11.15.....	σ, S	g	+113.1	−100.0	558
1926 Feb. 19.20.....	σ, S	f	+ 90.2	.....	566
1926 Feb. 28.12.....	B, S	p	+118.3	.....	575
1926 Mar. 1.09.....	σ	p	+ 75.8	.....	576
1926 Mar. 4.09.....	Lv, S	g	+ 71.2	.....	579
1926 Mar. 14.03.....	σ	g	+ 67.8	− 81.1	589
1926 Apr. 10.07.....	σ, S	p	+ 26.5	.....	616
1926 Apr. 12.08.....	Lv, S	f	+ 44.6	.....	618
1926 Apr. 14.06.....	σ, S	g	+ 33.9	.....	620
1926 Oct. 13.46.....	σ, S	f	− 30.5	.....	802
1926 Oct. 15.45.....	σ, S	g	− 12.0	.....	804
1926 Oct. 21.47.....	σ, S	f	− 9.6	.....	810
1926 Oct. 26.46.....	σ, S	p	− 8.5	.....	815
1926 Nov. 2.46.....	M, S	g	− 30.8	.....	822
1926 Nov. 23.38.....	σ, S	g	− 40.5	.....	843
1926 Dec. 30.28.....	B, S	g	− 54.2	+ 75.3	880
1927 Jan. 7.23.....	σ,H,S	g	− 58.3	.....	888
1927 Jan. 14.22.....	σ,H,S	p	− 48.4	.....	895
1927 Jan. 15.24.....	σ,M,S	g	− 48.4	.....	896
1927 Jan. 30.19.....	σ,H,S	f	− 42.7	.....	911
1927 Feb. 4.19.....	M,B,S	f	− 62.5	.....	916
1927 Feb. 10.21.....	M, S	g	− 59.3	.....	922
1927 Feb. 12.12.....	B,M,S	p	− 35.3	.....	924
1927 Feb. 22.09.....	σ,H,S	p	− 60.4	.....	934
1927 Feb. 23.10.....	M, S	g	− 63.3	+105.0	935
1927 Feb. 23.15.....	M, S	g	− 59.7	+ 61.3	935
1927 Feb. 23.20.....	M, S	g	− 56.0	.....	935
1927 Mar. 4.07.....	M, S	g	− 81.3	+ 95.4	944
1927 Mar. 4.12.....	M, S	g	− 74.8	+125.3	944
1927 Mar. 5.06.....	σ,H,S	g	− 81.3	+146.6	945
1927 Mar. 8.18.....	M, S	g	− 78.0	+192.1	948

TABLE I—*Continued*

Date G.C.T.	Observer	Qual.	Vel. I	Vel. II	Phase
1927 Mar. 9.07.....	σ,H,S	g	− 66.8	+146.6	949
1927 Mar. 10.10.....	M, S	p	− 74.9	+ 94.6	950
1927 Mar. 18.04.....	σ,H,S	g	− 84.5	+103.5	958
1927 Mar. 28.05.....	M,H,S	g	− 84.6	+116.9	968
1927 Apr. 6.06.....	σ,H,S	g	− 72.1	+182.3	977
1927 Apr. 7.05.....	M,H,S	f	− 63.4	+191.5	978

The names of the observers and the quality of the plates are designated as follows: B=S. B. Barrett, F=E. B. Frost, Fox=Philip Fox, H=C. Hujer, Lv=C. T. Elvey, M=W. W. Morgan, S=F. R. Sullivan, σ=O. Struve; g=good, f=fair, p=poor. The phases are expressed in days and are counted from J.D. 2424000.000 G.C.T.

The measures of C are necessarily very uncertain. Nevertheless, they show such a range in velocity that I am inclined to believe that C has also an invisible companion, D. If this is correct, the period of D around C must be somewhere near eight days, with K equal to

TABLE II

ORBITAL ELEMENTS FOR THE LONG PERIOD OF 27 CANIS MAJORIS

Velocity of system.....	γ	+39.2 km/sec.	
Period.....	P	1165 days	
Time of periastron.....	T	Phase, 1075 days=J.D. 2425075	
Longitude of periastron.....	ω	214°	
Eccentricity.....	e	0.33	
Semi-amplitude.....	K_1	110.5 km/sec.	
Mass function.....	$\frac{(m_C+m_D)^3}{(m_A+m_B+m_C+m_D)^2}\sin^3 i$		119 ⊙
Minimum mass.....	$(m_A+m_B+m_C+m_D)\sin^3 i$		950 ⊙
Mass-ratio.....	$(m_C+m_D)/(m_A+m_B)$		1
Semi-major axis.....	$(a_1 \sin i)$	1,590,000,000 km	

at least 50 km/sec. However, in view of the small number of measures on C and their uncertainty, I have not used them for the determination of any of the orbits. They indicate with a reasonable degree of certainty that the mass of A+B is only very little larger than that of C+D. Table I contains the results of the measurements, while Table II gives the orbital elements of the long-period system.

The mass function is the largest of any spectroscopic binary for which the orbit has been determined. Assuming the evidence of the fainter spectral component, C, according to which the mass of C+D is nearly equal to that of A+B, we find for the total minimum mass of the system a value of nine hundred and fifty times that of the Sun.

This value is so much larger than anything found hitherto that it seems interesting to investigate whether it can be due to any possible error in the elements. The period cannot be much in error. As we have seen, a shorter value for P does not satisfy the observations. One of much longer duration would make the mass still larger. The value of K is certainly not overestimated. If anything, it can only be larger than the adopted value, which would also lead to a larger mass. The only element that can appreciably affect the value of the mass is the eccentricity. This depends partly on the unobserved steep branch of the velocity curve. But here, too, a large error does not seem possible. An inspection of E. S. King's[1] set of theoretical velocity curves shows that the observed parts of such a curve cannot well be reconciled with an eccentricity greater than 0.4–0.5. At the same time an increase in e must necessarily be accompanied by a corresponding increase in K. The resulting total mass will therefore be affected but slightly. Even for $e=0.5$ or $e=0.6$ the total minimum mass will be several times larger than that of any other known spectroscopic binary.

It is well to remember that according to our conception of this system there are four separate stars. The average minimum mass of each component will therefore be only one-quarter of the total mass, or about two hundred and thirty-eight times that of the Sun.

The value of $(a \sin i)$ is 1590 million km, or about 10 astronomical units. The separation of the two doubles A+B and C+D would be twice this distance since their masses are nearly equal. The parallax is not known, but the spectroscopic absolute magnitude, derived from the type of component A, namely, B5n, is -0.5.[2] The total visual magnitude is 4.7. It seems probable that the visual magnitude of the brightest component, A, is at least 5.3. Under such

[1] *Annals of Harvard College Observatory*, **81**, 231, 1920.

[2] Adams and Joy, *Astrophysical Journal*, **57**, 297, 1923.

assumptions the distance is 145 parsecs and the angular separation is 0".14. This should be within reach of large telescopes. However, some doubt arises as to the luminosity of this star. The presence of bright lines may point to a greater absolute luminosity and consequently to a smaller angular separation.

THE SHORTER PERIOD

The oscillation of the shorter period of A can now be studied a little more in detail. I have corrected all measures for the motion of A+B around C+D. These corrections are somewhat problematic in view of the uncertainty attached to the elements, but this is the best that can be done at present. Figure 2 shows the results. The oscillations are very clearly visible during the season 1925–1926 and again in 1927, but in the latter half of 1926 the velocities do not fit so well. The slope of the curve in 1926–1927 is probably due to the uncertainty of the applied corrections. However, in view of the preliminary character of this study, I have not attempted to adjust the long-period orbit in such a way as to fit the short oscillations. The velocities of 1925–1926 are based on very consistent double measures, and the reality of the oscillation seems to me unquestionable. Preliminary circular elements of this oscillation are given in Table III.

TABLE III

ELEMENTS OF SHORT-PERIOD OSCILLATION OF 27 CANIS MAJORIS

Period	P	121 days
Time of maximum velocity	T	Phase, 458 days = J.D. 2424458
Semi-amplitude	K	25 km/sec.
Semi-major axis	$a \sin i$	41,000,000 km

It may be of interest to compare the relative distances in the two orbits in this system. We can assume that for a short time while C+D is in periastron with respect to A+B, its motion is circular with a distance of about 900 million km from the center of gravity of A and B. Assuming the mass of B to be infinitesimal, the integral of Jacobi becomes applicable. Since in this system $m_A+m_B \geq m_C+m_D$, it is obvious that the point X, where the surfaces of zero relative velocity unite, is situated in such a way that $CX \leq AX$. At

the same time the distance AB can never be more than about one-eighteenth of the distance AC. Therefore, it is probable that B belongs permanently to A and that no danger arises to this closer system from the approach of C near periastron. This assumes tacitly that the infinitesimal body B revolves around a hypothetical mass A in exactly the same circular orbit in which the real and unperturbed

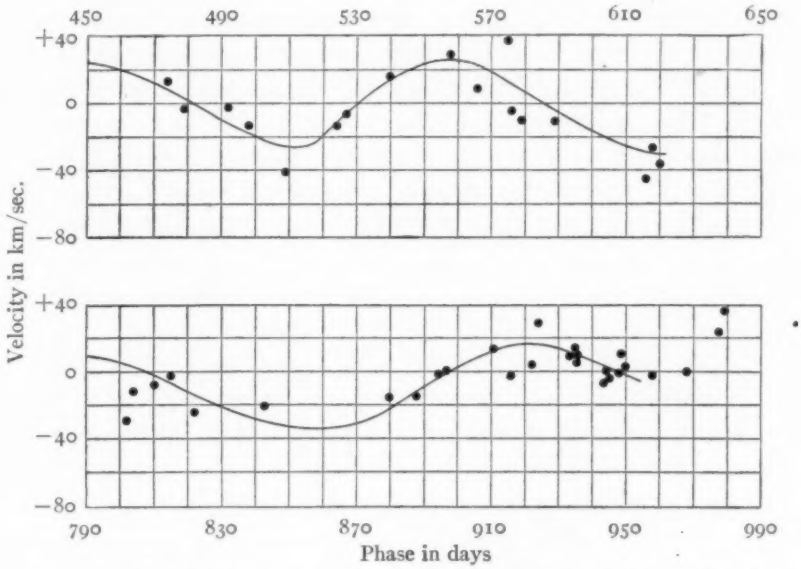

FIG. 2.—Short-period oscillation of component A of the spectroscopic multiple star 27 Canis Majoris.

B would move if its mass were equal to that of the real A. The mass-ratio m_B/m_A is not known, but it seems very unlikely that it should be so different from unity as to bring the orbit of B outside the critical point X. The same reasoning applies, of course, also to the star D revolving around C, only in this case conditions are such that the orbit will be even more stable than that of B around A.

The only spectroscopic multiple star yet known in which the amplitude of the shorter period is smaller than that of the long period is 27 Canis Majoris. It is true that in a few binaries there have been found oscillations of short period with small amplitude, but these are almost certainly due to some other cause and not to

the existence of a third body. In nine other systems which can safely be assumed to be actually triple, the long period has the smaller value of K, a result to be expected from Kepler's third law if the masses of all components are equal and if the inclinations of the two orbits are alike. The small value of K in the system of A and B may thus be explained if the inclinations are very different, or if m_A is much larger than m_B.

It will be seen from Figure 1 that the velocity curve at minimum has never been observed. Unfortunately, the declination of this star is so low that we were forced to discontinue the observations on April 7. The next minimum, in 1930, will be placed even more unfavorably and not until 1933.7 will conditions be favorable for observing the minimum of velocity. Nevertheless, it is expected that the observations during the coming fall and winter will considerably strengthen the ascending branch of the velocity curve. They will also give additional material for a study of the shorter oscillations.

CONCLUSIONS

In view of the very unusual value of the mass-function in this system, it is well to remember that the observed shifts of spectral lines are not always due to Doppler effect. In the first place, it is necessary to consider the possibility of complications arising from the presence of bright lines. As far as our Yerkes plates are concerned I cannot conceive how the bright lines can be responsible for the observed shifts. In the hydrogen lines, caution is of course needed, since at least on some of the plates $H\beta$ seems definitely to possess bright edges. Although all other hydrogen lines appear dark, it is conceivable that the position of the absorption lines may be influenced by the existence of very faint emission bands, invisible on the background of the continuous spectrum. But, in this star, the radial velocities are derived chiefly from the helium lines. These appear perfectly dark on all of our plates, and in no other case would I have felt the slightest hesitancy of attributing the line-displacements to actual motion in the line of sight. It is necessary, however, to mention at this place that Merrill, in his observations, had thought that the helium lines were possibly also accompanied by bright edges. Our measures of the line Mg 4481 also agree within errors

of measurement with the other lines. But perhaps the strongest argument against the influence of bright lines lies in the fact that even the two calcium lines 3933 and 3968 agree with the other lines. It would then be necessary to assume that all lines in 27 Canis Majoris are equally distorted by the presence of bright lines—a fact unknown to me in any other star.

We are thus confronted in this system with one of three seemingly impossible alternatives: (1) The mass is incredibly large. (2) There exist unknown effects, possibly connected with the presence of bright lines, which distort all the absorption lines in exactly the same way. (3) The period is almost exactly one day. This alternative was found practically excluded by the evidence in this paper. But even if it were correct it would indicate a rather uncommon sort of a binary, for all other real B-type double stars have $P > 1.3$ days.

YERKES OBSERVATORY
April 1927

STARS WHOSE SPECTRA HAVE BRIGHT IRON LINES[1]

By PAUL W. MERRILL

ABSTRACT

Classification of stellar spectra having bright iron lines.—These spectra may be classified in the following groups: (1) long-period variables; (2) peculiar stars of classes G, K, and M; (3*a*) class Be normal; (3*b*) class Be peculiar; (4) novae. Available information concerning these stars is summarized, and a few unpublished observations are recorded.

Lists of stars in groups 2, 3*a*, and 3*b* are given, with references to published descriptions. New data are recorded for Z Canis Majoris (H.D. 53179), and B.D.+14°3887. It seems possible that stars of group 3*b* (with outstanding bright lines and other peculiarities) have fainter absolute magnitudes than those of 3*a*.

Lines of the ionized atom are of more frequent occurrence than those of the neutral atom. This fact is briefly discussed.

Hydrogen stands by itself among the chemical elements in the frequency with which its emission lines are found in stellar spectra. Iron comes next and helium third, unless we count long-period variables at phases other than maximum, in which case magnesium and silicon might outrank helium. The properties of bright hydrogen lines in stellar spectra are fairly well known, as these lines have been extensively investigated, and many data concerning them have been published.

Bright iron lines appear in quite different types of stars, and references to them are widely scattered through astronomical literature. The present paper attempts to summarize the available information concerning the occurrence of these lines, and in addition records a few unpublished observations.

Stars in whose spectra bright iron lines have been found may be classified as follows:

1. Long-period variables. Examples, *o* Ceti and R Cygni
2. Peculiar stars of classes G, K, and M. Examples, T Tauri, W Cephei, and VV Cephei (Boss 5650)
3. Class Be
   - *a*) Normal. Examples, γ Cassiopeiae and β Monocerotis (brightest component)
   - *b*) Peculiar. Examples, η Carinae and XX Ophiuchi (H.D. 161114)
4. Novae

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 334.

Recent progress in the analysis of spectra has emphasized the importance of distinguishing between lines of the neutral and of the ionized atom. The difference in behavior in stellar spectra of various lines arising from the same chemical element has, of course, impressed itself upon observers for many years, and has been a most important factor in hastening the interpretation of line spectra in terms of the structure of the atom.

The fact that in various types of stars having bright iron lines we are dealing chiefly with enhanced lines (i.e., those of the ionized atom) is thus of considerable interest. Long-period variables are the only stars in which bright lines of the neutral iron atom appear in any strength, and in these stars enhanced lines also are present.

We now proceed to a brief description of the characteristics of the iron lines in the various groups of the foregoing classification.

1. LONG-PERIOD VARIABLES

The neutral and ionized lines occur under different circumstances and must be discussed separately.

Lines of the neutral atom. Fe I.—During the time of decreasing light, the spectra of variables of classes Me and Se exhibit a number of unusual bright lines, among which are the extreme low-temperature lines of iron. In the spectral region λ 4200–λ 4500, King's list of persistent low-temperature lines[1] is so consistently represented in the variables[2] as to leave very little doubt concerning the identification.

Two of the most conspicuous bright lines present during the time of decreasing light[3] lie near the positions of the iron lines λ 4202.03 and λ 4307.91. These lines are believed by several observers actually to be iron lines, and, in addition to the agreement of the laboratory and stellar wave-lengths, the careful discussion of identifications in *o* Ceti by Joy[4] has brought out several indirect

[1] *Mt. Wilson Contr.*, No. 247; *Astrophysical Journal*, **56**, 318, Table V, 1922.

[2] *Mt. Wilson Contr.*, Nos. 311 and 325; *Astrophysical Journal*, **63**, 281, 1926, and **65**, 23, 1927.

[3] *Mt. Wilson Contr.*, Nos. 200, 265, 311, 325; *Astrophysical Journal*, **53**, 185, 1921; **58**, 195, 1923; **63**, 281, 1926; **65**, 23, 1927.

[4] *Mt. Wilson Contr.*, No. 311; *Astrophysical Journal*, **63**, 281, 1926.

but plausible arguments in favor of this view. Nevertheless some doubt may remain[1] until these lines are shown by laboratory experiments to be outstanding under special circumstances, or until the presence in emission of certain related iron lines is recorded in the variables.

Enhanced (ionized atom) lines. Fe II.—According to Joy,[2] the identification of several bright lines in the spectrum of *o* Ceti near maximum, with ionized iron, "may be considered as entirely probable." This may apply to numerous other Me variables as well, although I think that the lines in question are less prominent in some of them. In the spectra of Se variables, on the other hand, the bright iron lines are decidedly more conspicuous, several of them, in particular λλ 4583, 4924, and 5018, being present on numerous spectrograms of these stars.[3] They are especially prominent in S Cassiopeiae and R Cygni. In several variables, the bright enhanced iron lines seem strongest near maximum, as would be expected, but in R Cygni they persist throughout a considerable portion of the light-cycle.

2. PECULIAR STARS OF CLASSES G, K, AND M

Stars of these classes which are known to exhibit bright iron lines are listed in Table I. The iron lines are those of the ionized atom, including λλ 4179, 4233, 4549, 4584, 4924, 5018, as well as other weaker lines. The hydrogen lines are bright, as are also numerous lines of unknown origin. Concerning VV Cephei (Boss 5650), W Cephei, and H.D. 42474, Adams, Joy, and Humason[4] say, "There can be little doubt that the spectrum of these stars is closely allied to that of the well known southern variable, *η* Carinae. A comparison of the results with those published by Moore and Sanford for the latter star[5] shows all of these bright lines to be present in much the same relative intensity." Many of the same lines are found also in the spectra of H.D. 45677[6] and other peculiar stars of class Be.

[1] Baxandall, *Observatory*, **46**, 82, 1923. [2] *Loc. cit.*

[3] *Mt. Wilson Contr.*, No. 325; *Astrophysical Journal*, **65**, 23, 1927.

[4] *Publications of the Astronomical Society of the Pacific*, **34**, 176, 1922.

[5] *Lick Observatory Bulletins*, **8**, 55 (No. 252), 1913.

[6] *Publications of the Astronomical Society of the Pacific*, **37**, 163, 1925.

3. CLASS Be

Many spectra of class B show bright hydrogen lines, and in about one-eighth of these, bright iron lines also have been observed. We may, for convenience, divide the stars with bright iron lines into two groups according to the appearance of the bright lines. In the first group the bright hydrogen lines are of the "normal," symmetrical, or nearly symmetrical type described as S, D?, or D in *Contribution* No. 294.[1] The iron lines have about the same structure as the hydrogen lines, but are much weaker and usually exhibit small contrast with the continuous spectrum. This group includes

TABLE I

STARS OF CLASSES G, K, M, WITH BRIGHT IRON LINES

Star	No.	R.A. 1900	Dec. 1900	Mag.	Type	Notes
T Tauri.....	N.G.C. 1555	$4^h 16^m.1$	$+19° 17'$	(10)	Gpe	1
W. Geminorum.	H.D. 42474	6 5.8	+23 14	7.4	M3ep	2
Boss 1985.....	H.D. 60414, 5	7 29.2	−14 18	5.1	M3ep	3
R Cor. Austr...	N.G.C. 6729	18 55.2	−37 5	10–13	Gpe	4
Boss 5481.....	H.D. 203338, 9	21 16.5	+58 12	5.8	(M1+B)e	3
VV Cephei.....	H.D. 208816	21 53.8	+63 9	5.4	M2ep	2, 5
W Cephei.....	H.D. 214369	22 32.6	+57 54	8.6–9.3	K5e	2

NOTES TO TABLE I

1. *Publications of the Astronomical Society of the Pacific*, **32**, 59, 1920.
2. *Ibid.*, **34**, 175, 1922.
3. *Ibid.*, **37**, 161, 1925.
4. *Mt. Wilson Contr.*, No. 241; *Astrophysical Journal*, **56**, 181, 1922.
5. *Publications of the Astronomical Society of the Pacific*, **33**, 263, 1921.

γ Cassiopeiae, ϕ Persei, β Monocerotis, μ Centauri (prior to 1904), and other bright and well-known stars of class Be. Stars of this kind are listed in Table II.

The list will doubtless be extended by future work, as many bright-line B-type stars probably remain to be discovered. Moreover, not all known Be stars have been observed in such a way as to bring out the broad, weak iron lines here considered. This would require widened spectrograms on emulsions of considerable contrast.

[1] *Astrophysical Journal*, **61**, 416, 1925. See also *Transactions of the International Astronomical Union*, **1**, 100, 1922.

The identification of iron lines in this type of spectrum was apparently first made by N. Lockyer and F. E. Baxandall in the stars μ Centauri and γ Cassiopeiae.[1] A spectrogram of μ Centauri obtained at Mount Wilson in June, 1924, shows that the recent disappearance of the bright hydrogen lines, noted by several observers, was accompanied by the disappearance of the bright iron lines.

TABLE II

NORMAL BE STARS WITH BRIGHT IRON LINES

Star	H.D.	R.A. 1900	Dec. 1900	Mag.	Type	Notes
γ Cass	5394	$0^h 50^m.7$	$+60° 11'$	2.2	Boe	1, 2, 3
ϕ Persei	10516	1 37.4	+50 11	4.2	Boe	2, 3
.....	20336	3 11.2	+65 17	4.8	B3e	2, 3
.....	21212	3 20.3	+62 9	8.7	B2e	4
ψ Persei	22192	3 29.4	+47 51	4.3	B5e	2, 3
11 Camelop.	32343	4 57.4	+58 50	5.3	B3e	2
.....	35345	5 19.0	+35 33	8.4	B2e	4
25 Orionis	35439	5 19.6	+ 1 45	4.7	B3e	3
ζ Tauri	37202	5 31.7	+21 5	3.0	B3e	3
.....	41335	5 59.4	− 6 42	5.1	B2e	2
β Mono. (pre.)	45725	6 24.0	− 6 58	4.7	B2e	2
ω Can. Maj.	56139	7 10.7	−26 35	3.8	B3e	2
.....	65875	7 55.8	− 2 36	6.4	B3e	4
r Puppis	68980	8 9.7	−35 35	4.8	B3e	2
μ Centauri	120324	13 43.6	−41 59	3.3	B2(e)	1, 3
χ Ophiuchi	148184	16 21.2	−18 14	4.8	B3e	2
.....	190944	20 2.3	+46 24	8.8	B2e	4
π Aquarii	212571	22 20.2	+ 0 52	4.6	B1e	3
β Piscium	217891	22 58.8	+ 3 17	4.6	B5e	2
.....	225095	23 58.3	+55 0	7.6	B1e	4

NOTES TO TABLE II

1. *Proceedings of the Royal Society of London*, A, **74**, 548, 1905.
2. *Lick Observatory Bulletins*, **7**, 177 (No. 237), 1913.
3. *Monthly Notices, R.A.S.*, **85**, 594, 1925.
4. Unpublished observations at Mount Wilson.

The spectra of the second group of B-type stars with bright iron lines show a more pronounced departure from ordinary B-type spectra than do those of the first group. The bright lines are more outstanding, and peculiarities, such as those of the type of P Cygni, are often present. Stars of this kind are listed in Table III.

[1] *Proceedings of the Royal Society of London*, A, **74**, 548, 1905.

TABLE III

PECULIAR BE STARS WITH BRIGHT IRON LINES

Star	No.	R.A. 1900	Dec. 1900	Mag.	Notes
Comp. *o* Ceti		$2^h 14^m.3$	$-3°\ 26'$	10–11	1
	H.D. 45677	6 23.7	−13 0	7.5	2
AY. Mon	H.D. 45910	6 25.2	+ 5 57	6.7	3
R Mono	N.G.C. 2261	6 33.7	+ 8 49	(13)	4
	H.D. 51480	6 52.4	−10 41	7.0	5
Z Can. Maj.	53179	6 59.0	−11 24	(9.1)	11
η Carinae	93308	10 41.2	−59 10	7–8	6
XX Ophiuchi	161114	17 38.6	− 6 14	9.6–10.7	7
DM. −27°11944		17 41.9	−27 59	9.0	5
B.D. +14°3887		19 17.0	+14 42	9.5	12
B.D. +11°4673	207757	21 46.2	+12 9	(7.6)	8
Z Androm.	221650	23 28.8	+48 16	8.3–11.4	9
Comp. R Aquarii		23 38.6	−15 50	9–10	10

NOTES TO TABLE III

1. *Mt. Wilson Contr.*, No. 311; *Astrophysical Journal*, **63**, 337, 1926.

2. *Publications of the Astronomical Society of the Pacific*, **37**, 163, 1925.

3. *Ibid.*, **35**, 145 and 303, 1923.

4. *Lowell Observatory Bulletins*, **3**, 63 (No. 81), 1918.

5. *Mt. Wilson Contr.*, No. 295; *Astrophysical Journal*, **61**, 418, 1925.

6. *Lick Observatory Bulletins*, **8**, 55 (No. 252), 1913.

7. *Publications of the Astronomical Society of the Pacific*, **36**, 225, 1924, and **38**, 45, 1926.

8. *Publications of the Astronomical Observatory of the University of Michigan*, **2**, 71, 1916.

9. The presence of bright iron lines in this spectrum was mentioned by J. S. Plaskett at the Pasadena meeting of the American Astronomical Society in September, 1923. A paper by H. H. Plaskett on this spectrum will appear in Volume IV of the *Publications of the Dominion Astrophysical Observatory*.

10. *Publications of the Astronomical Society of the Pacific*, **39**, 48, 1927.

11. *Z Canis Majoris, B.D.−11°1760.*—Miss Cannon's discovery of the bright lines $H\beta$ and $H\gamma$ was announced in *Harvard Circular*, No. 178. The following remark is found in the *Henry Draper Catalogue:* "The lines $H\beta$ and $H\gamma$ are bright. The dark lines are very faint, but helium lines are certainly present. The line K is very strong for Class B." In *Harvard Circular*, No. 225, it is stated that this star is an irregular variable and that its light-curve bears some resemblance to that of R Coronae Borealis.

Spectrograms were obtained at Mount Wilson on October 30, 1925, and January 18, 1927. A one-prism spectrograph with 10-inch camera was employed. The magnitude of the star on both dates was about 9.

On the first plate, the hydrogen lines and several enhanced iron lines are bright, with broad dark components on their violet sides. The bright iron lines include λλ 4173, 4179, 4233, 4352, 4385, 4417?, 4451, 4490 (blend), 4508, 4515, 4521 (blend), 4549, 4556?, 4584, 4629, 4924, 5018. The absorption components are not seen in all cases.

Feeble bright lines are seen in the positions of the following strong lines in the enhanced titanium spectrum: λλ 4395, 4444, 4469. They probably have the same structure as the iron lines.

On the second plate, the bright lines, especially those of iron, are less intense, while the absorption lines of titanium are stronger, twelve or more being measurable. The behavior of this spectrum thus in a measure resembles that of the "iron star" XX Ophiuchi (H.D. 161114).[1]

The apparent radial velocity corresponding to the displacements of the bright portions of the hydrogen lines is +67 km/sec. From about ten iron lines, it is +45 on the first plate, and +75 on the second. The difference probably reflects the relative increase in strength of the dark components. It is not certain that any of these results represents the actual velocity of the star.

The dark lines are considerably displaced toward the violet. The measured differences between the effective centers of the emission and absorption components of the hydrogen lines are as follows: $H\delta$, 4.0 A; $H\gamma$, 4.3 A; $H\beta$, 6.1 A. The iron lines, being less intense, give smaller differences. A smooth curve drawn through the scattering points plotted from the measured separations of ten iron lines has the following co-ordinates: λ 4200, 2.7 A; λ 4600, 3.2 A; λ 5000, 4.2 A. For both hydrogen and iron, the separations are represented approximately by a function varying as the square of the wave-length.

The apparent position of this star is quite near that of the somewhat similar star H.D. 51480,[2] and not far from H.D. 45677, but this may be a coincidence, as the three objects lie close to the central line of the Milky Way. In some respects the spectrum of Z Canis Majoris (H.D. 53179) is intermediate between that of H.D. 51480 and of Cordoba DM. −27°11944.[2]

12. *B.D.+14°3887.*—The bright *Ha* line in this spectrum was discovered at Mount Wilson from objective-prism photographs.[3] Observations with a one-prism slit-spectrograph and 18-inch camera have been obtained on the following dates: September 20, 1921; July 4, 1923; July 5, 1925. They show only the usual photographic region. The spectra are narrow and somewhat underexposed.

The bright hydrogen lines are strong, narrow, and apparently symmetrical. Dark components are not distinctly visible. Eight or ten bright enhanced lines of iron are present. Most of them are weak and appear as uncertain condensations in the narrow continuous spectrum. On better photographs, such as those usually obtained for brighter stars, the iron lines would doubtless be rather conspicuous.

The hydrogen lines, as well as those due to iron, are narrower and stronger than in the stars of the normal Be group (Table II). The spectrum is probably the same at the times of the three photographs.

The measured displacements of the bright $H\beta$ and $H\gamma$ lines give, in the mean, +33 km/sec. for the radial motion. The bright iron lines give +27 km/sec. These values doubtless agree within the errors of determination.

It is difficult to define precisely the distinction between the "normal" and "peculiar" Be spectra listed in Tables II and III, respectively. There may or may not be a fundamental difference be-

[1] *Publications of the Astronomical Society of the Pacific*, **38**, 45, 1926.

[2] *Mt. Wilson Contr.*, No. 295; *Astrophysical Journal*, **61**, 418, 1925.

[3] *Mt. Wilson Contr.*, No. 294; *Astrophysical Journal*, **61**, 389, 1925.

tween the two groups. The normal Be stars are much more closely related to ordinary dark-line B-type stars than are those of the other group. This is evidenced not only by the general appearance of the spectra, but by the fact that some of them, e.g., Pleione and μ Centauri, have changed into ordinary dark-line spectra by the fading of the bright lines. This seems to have occurred without notable changes in other features of the spectrum or appreciable variation of the total light. A number of spectra in the peculiar group also have shown variations, but of a different and more complex nature, which seem, in several instances, to have accompanied changes in the integrated brightness.

It is possible that the stars of the second group have a considerably lower mean absolute magnitude than those of the first. The apparent magnitudes in Table III average considerably fainter than those in Table II. The greater ease of detection of very strong bright lines may be partly responsible for this, but the absence of apparently bright stars from Table III, as compared with Table II, suggests a lower intrinsic brightness. Two of the stars in Table III are associated with long-period variables whose absolute magnitude at maximum is probably about zero. Joy,[1] and Merrill and Strömberg,[2] have pointed out that the peculiar bright-line companion of *o* Ceti appears to have an absolute magnitude about +6. Similarly, the bright-line star closely associated with R Aquarii[3] is several magnitudes fainter than the variable star at maximum.

4. NOVAE

The occurrence of bright lines of ionized iron in the spectra of novae is well known. The lines are broad but apparently occupy their normal positions. At an early stage they are accompanied by dark lines on their violet edges. For a description of the complicated changes which these lines undergo, the original memoirs on novae spectra must be consulted.[4]

[1] *Mt. Wilson Contr.*, No. 311; *Astrophysical Journal*, **63**, 339, 1926.

[2] *Mt. Wilson Contr.*, No. 267; *Astrophysical Journal*, **59**, 106, 1924.

[3] *Publications of the Astronomical Society of the Pacific*, **39**, 48, 1927.

[4] For example, Nova Geminorum: Stratton, *Annals of the Solar Physics Observatory, Cambridge*, **4**, 1, 1920; Wright, *Publications of the Lick Observatory*, **14**, 27, 1926.

It is rather curious that the stronger arc lines of iron do not occur more frequently in emission in stellar spectra. They are, of course, prominent in absorption in the spectra of classes F, G, K, M, N, and S, and one might expect them to show in emission more frequently than any other iron lines. This is, however, decidedly not the case. Two or three of the strongest lines were faintly present in emission in the spectrum of XX Ophiuchi (H.D. 161114) when the enhanced lines were very strong.[1] This and the well-known cases of λ 4202 and λ 4308 in long-period variables are the only observations which come to mind. In the outer atmospheres of most stars in which conditions favor bright lines, the iron vapor is probably too thoroughly ionized to permit neutral lines to show in emission. In other cases, the low density of the stellar atmosphere may tend to suppress the ordinary arc lines, as in King's observations of the high-current arc in vacuum.[2]

Bright lines of the ionized iron atom occur in novae and in stars of classes B, G, K, M, and S. They are very rare[3] except in stars near the extremes of the temperature sequence. Their presence is probably an indication of high temperature or low density. In all stars in which they have been found, the hydrogen lines also are bright.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
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NOTE ADDED TO PROOF.—Since this paper was written, Mr. Joy has discovered the existence of bright iron lines in the spectrum of the short-period variable W Serpentis (R.A. $19^h\ 4^m\ 1$, Dec. $-15°\ 34'$), at the time of minimum light.

[1] *Publications of the Astronomical Society of the Pacific*, **36**, 225, 1924.

[2] *Ibid.*, **38**, 235, 1926.

[3] Rare, that is, in the integrated light. Doubtless they are freely emitted in certain portions of many stars as, for example, in the solar chromosphere. If conditions were such as to make the light of the chromosphere sufficiently important in the total radiation between certain wave-lengths, the sun would then be a bright-iron-line star.

SPECTROGRAPHIC ORBITS OF THE TWO COMPONENTS OF BOSS 5683[1]

By ROSCOE F. SANFORD

ABSTRACT

Spectrum.—Star B of the visual system Σ 2873 is a *spectroscopic binary* in which two spectra of about class G4 are at times distinguishable and measurable.

Orbit.—The spectroscopic orbit of the primary and the semi-amplitude of velocity variation for the secondary have been found from thirty-eight spectrograms (Table I) made with the 60-inch reflector. The *orbit is circular*, with a period of 1.1522019 days; the semi-amplitudes of velocity variation for primary and secondary are 105.5 and 112.4 km/sec., respectively, and the velocity of the system −17.0 km/sec. A velocity diagram is shown in Fig. 1. The elements give $(a_1+a_2)\sin i = 3{,}470{,}000$ km; $m_1 \sin^3 i = 0.65\odot$; and $m_2 \sin^3 i = 0.61\odot$ (Table II). The velocity of the system here found is 5 km/sec. greater, algebraically, than that derived for star A, a difference hardly too large to attribute to the respective probable errors, although part of it may find a legitimate explanation in the orbital motion of the components of the visual system. Attention is called to the possibility of variability by eclipse.

This is star B of the visual system Σ 2873[2] (1900, α $22^h1^m.9$, $\delta+82°23'$, mag. 7.3 G4p). Both A (Boss 5682) and B have been found to have the same proper motion, but during the fifty years that the stars have been observed no certain evidence of orbital motion has been noted. Five spectrograms of star A made at this observatory gave the apparently constant radial velocity −22.7 km/sec.[3] Its spectral class is F6, apparent magnitude 7.1, and absolute magnitude 3.5.[4] The obvious conclusion that star B has a still fainter absolute magnitude has been borne out by the evidence of its spectrum, for this gives $M = 4.8$.[4] In addition, it was soon noticed that the radial velocities from the different plates were certainly unlike, and it was later announced[5] as a spectroscopic binary which at times shows the spectral lines of both components.

The variation in radial velocity of the two components was at first taken as evidence of a period of several days. As no such period could be found which would predict the phases for very long, an

[1] *Contributions from the Mount Wilson Observatory*, No. 333.

[2] H.D. 209943; βGC. 111514.

[3] *Mt. Wilson Contr.*, No. 258, p. 25; *Astrophysical Journal*, **57**, 173, 1923.

[4] *Mt. Wilson Contr.*, No. 199, p. 76; *Astrophysical Journal*, **53**, 88, 1921.

[5] *Publications of the Astronomical Society of the Pacific*, **31**, 42, 1919.

effort was finally made to obtain two spectrograms on the same night. This was accomplished on August 16, 1926, the two plates having mid-exposures that differ by a little more than six hours

TABLE I

OBSERVATIONS OF BOSS 5683

PLATE NO.	DATE	G.M.T.	PHASE	VELOCITY		O−C PRIM.	WT.
				Prim.	Sec.		
			days	km/sec.	km/sec.	km/sec.	
γ 5238.....	1916 Nov. 9	15^h41^m	0.252	− 30.8	.....	−34	0.5
6081.....	1917 July 8	23 26	0.765	− 11.2	.....	+59	0.5
6141.....	Aug. 31	22 38	0.576	−123.5	.....	− 1	0.5
6267.....	Oct. 5	19 30	0.878	− 7.0	.....	+ 2	1.0
6450.....	Dec. 5	17 00	0.707	−104.1	.....	− 7	1.0
6529.....	1918 Jan. 2	16 12	1.021	+ 43.1	− 97.7	−20	1.0
7497.....	Oct. 23	18 30	0.150	+ 66.6	−111.2	+11	1.0
9489.....	1920 Aug. 28	17 15	1.052	+ 79.6	− 92.1	+ 6	0.5
9498.....	Aug. 29	16 54	0.885	− 13.0	.....	− 8	1.0
9520.....	Sept. 1	23 43	0.713	− 79.9	+ 94.8	+15	0.5
10201.....	1921 June 14	21 51	0.886	− 26.6	.....	−22	0.5
10252.....	July 11	20 13	0.165	+ 57.1	− 76.4	+ 9	1.0
10256.....	July 12	19 39	1.141	+111.0	−112.1	+22	1.0
10265.....	July 13	20 42	1.032	+ 49.4	− 64.8	−17	0.5
11097.....	1922 June 7	23 18	0.608	−131.0	+ 87.8	−10	0.5
11101.....	June 8	22 52	0.438	− 94.6	.....	− 1	0.25
11121.....	July 2	20 59	0.161	+ 55.3	.....	+ 5	0.5
11127.....	July 3	20 22	1.136	+ 83.3	−126.8	− 5	0.5
11133.....	July 4	20 46	1.000	+ 52.5	− 78.1	− 2	0.5
11226.....	Aug. 5	23 24	0.849	− 18.5	.....	+ 7	1.0
11296.....	Sept. 2	22 36	1.151	+ 68.6	.....	−20	0.5
11303.....	Sept. 3	21 49	0.979	+ 37.0	.....	− 8	0.5
12330.....	1923 Dec. 16	16 6	0.789	− 44.6	.....	+14	1.0
12337.....	Dec. 17	16 24	0.648	−118.8	+110.2	− 4	1.0
13519.....	1925 July 5	20 00	1.061	+ 74.8	−114.4	− 1	1.0
13525.....	July 6	20 00	0.909	+ 13.2	.....	+ 5	1.0
13532.....	July 7	19 15	0.726	− 88.6	+ 43.3	+ 1	1.0
13538.....	July 8	19 58	0.603	−128.5	+102.4	− 7	1.0
13544.....	July 9	20 39	0.479	−124.6	+ 88.4	−16	1.0
13628.....	Aug. 6	23 24	0.950	+ 32.0	.....	+ 1	1.0
13629.....	Aug. 7	16 20	0.496	−107.8	+ 96.6	+ 5	1.0
13630.....	Aug. 8	18 02	0.414	− 82.0	+ 64.7	+ 2	1.0
13641.....	Aug. 10	17 30	0.087	+ 76.4	− 93.1	0	0.25
13653.....	Aug. 12	16 37	0.898	− 9.2	.....	−12	1.0
13943.....	Dec. 29	15 58	0.452	−112.2	+ 99.6	−13	0.5
14427.....	1926 Aug. 16	16 35	0.035	+ 88.6	−118.0	+ 2	1.0
14430.....	Aug. 16	23 19	0.316	− 23.0	.....	+10	1.0
14431.....	Aug. 17	16 27	1.030	+ 69.2	−104.2	+ 3	1.0

(Table I). The first of these shows a spectrum of double lines, and the second, one of single lines. The results from these two plates, in combination with the velocity found from that of August 17, taken

eighteen hours later, showed that the period could not be much greater than one day. Indeed this clue led finally to 1.1522019 days as the period best suited to assemble the velocities derived from the thirty-eight spectrograms made between November, 1916, and August, 1926.

All the plates were obtained with the 60-inch reflector and a one-prism spectrograph. The observational data are in Table I, which has two columns for the radial velocities. If the spectra are blended, a velocity appears only in the column for the primary. In some cases, although the two spectra were separated, only that of the primary could be measured. When two spectra of types as late as these are blended, difficulties arise which often diminish the accuracy of the velocities for the two components and sometimes prevent the measurement of the weaker component entirely. All these difficulties have been encountered in this case.

Careful consideration of the freehand velocity-curves drawn through the assembled observations resulted in the assumption of circular orbits. Furthermore, since the curve for the primary seemed much more accurate than that for the secondary, it was decided to determine all the elements, except the semi-amplitude of velocity-variation for the secondary, from the curve for the primary alone. The preliminary elements for the assumed circular orbit were therefore P, the period; T, the time when the primary attains maximum positive velocity; K_1, the semi-amplitude of velocity-variation for the primary; and, finally, γ, that value of the velocity which divides the radial velocity diagram into equal areas.

The first two values of the radial velocity in Table I gave large residuals which could have been considerably diminished by slightly increasing the period; but other considerations seemed to favor the adopted period, and the final correction of this element was left to the least-squares solution. For this the weights assigned are based upon the various characteristics of the individual plates which may affect the accuracy of the measures. The least-squares solution resulted in sensible corrections only to K_1 and P; but the application of these corrections reduced $[pvv]$ 40 per cent, the effect, in large measure, of the change in P upon the residuals for the first two plates. A second solution based on all but the first two velocities

also gave sensible corrections only in the case of K_1 and P, and of the same sign as before. Since these elements do not materially better the representation of the thirty-six values of the velocity employed, and are quite inferior to the first set in representing the first two velocities, the results of the original solution are adopted.

A value of K_2, the semi-amplitude of velocity-variation of the secondary, has been derived from the measures of velocity by a least-squares solution of the equation

$$C_2 = \gamma - K_2 \cos M ,$$

where C_2 is the measured velocity of the secondary, $\gamma = -17$ km/sec., the velocity of the system, and M the phase as reckoned for the primary, the weights being the same as appear in Table I. The resulting value, $K_2 = 112.4$ km/sec., seems, however, to be somewhat too small, because of the use of some values of C_2 that are unduly small but whose rejection would be an arbitrary procedure. Furthermore, the near equality of K_1 and K_2 does not seem compatible with the very considerable difference in the intensity of the two spectra when seen separated. Nevertheless, the value obtained above is retained.

The preliminary elements, corrections, and final elements, together with their probable errors and the functions of mean distance and mass, are:

Preliminary Elements	Corrections	Final Elements
P 1.1522019 days	+0.0000124 day	1.1522143±0.0000003 day
γ −16.0 km/sec.	−1.0 km/sec.	−17.0 km/sec.
T J.D. 2423213.380	−0.017 day	J.D. 2423213.363±0.003 day
K_1 112 km/sec.	−6.4 km/sec.	105.6±2.0 km/sec.
K_2		112.4 km/sec.
$(a_1+a_2)\sin i$		3,470,000 km
$m_1 \sin^3 i$		0.65 ⊙
$m_2 \sin^3 i$		0.61 ⊙

The last column in Table I gives the residuals for the primary as computed from the adopted elements.

Velocity-curves are given in Figure 1 for both components, although the elements upon which they are based, with the exception of K_2, are derived solely from the primary. The smaller circles indicate velocities for the primary; larger circles, those for the secondary.

The interval covered by the observations here represented includes 2886 revolutions in the orbits.

It is worthy of note that the velocity of this system (B of the visual pair) is -17.0 km/sec., whereas that for A, as mentioned in the beginning, is -22.7 km/sec. Attention should also be called to the fact that the velocities for the secondary would be better represented if its curve were raised somewhat; in other words, if its γ were algebraically larger. No explanation for this discordance in the γ-value for the two components is offered, except in so far as the

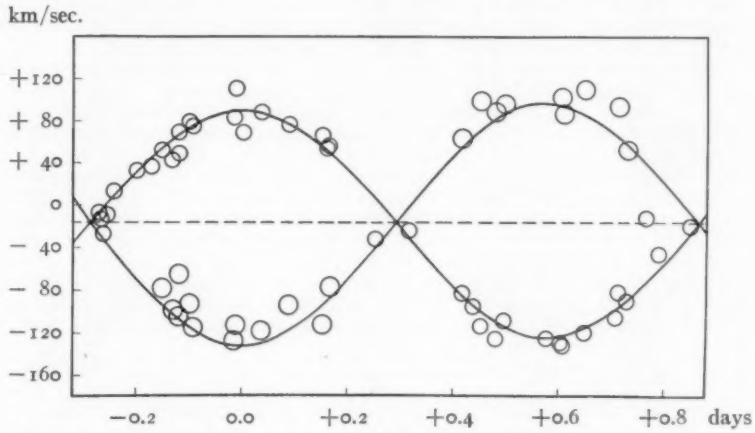

FIG. 1.—Velocity-curves for the spectroscopic binary Boss 5683 (Σ 2873 B)

fault may be traceable to the relative inaccuracy of the velocities for the secondary. Any weight that the secondary of the spectroscopic binary may have in determining the center-of-mass velocity for the system B can only accentuate the difference in velocity already shown to exist between stars A and B. The respective probable errors of the two velocities and the possibility of orbital motion in the visual binary would, however, suffice to explain this difference.

It would be of interest to observe this spectroscopic binary photometrically at appropriate epochs in order to test for a decrease in brightness produced by eclipse. The spectroscopic data are quite consistent with such a possibility.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
March 1927

ORBIT OF THE SPECTROSCOPIC BINARY 36 τ^9 ERIDANI

By O. STRUVE and C. HUJER

ABSTRACT

The *radial velocity* of 36 τ^9 Eridani was measured on 53 one-prism spectrograms. The *period* was found to *change* appreciably during the course of one year. Between September, 1926, and February, 1927, $P=0.85437$ day. This period does not satisfy our observations of 1924–1926, requiring a correction of +0.0009 day to bring them into agreement with the later observations. An average period of 0.8544075 day is indicated, but the deviation from this value in 1926–1927 is well marked.

The *orbital elements* were derived from the observations of 1926–1927, and a least-squares solution was carried through. The orbit is *circular;* the semi-amplitude of the variation in velocity is 35.7 km/sec., and the velocity of the system is +19.7 km/sec.

The lines of the *second component* could be measured on several plates and the resulting *mass-ratio is 0.35.*

The *silicon lines* λ 4128 and λ 4132, which are unusually strong in the spectrum of this star of type Ao, give the same velocity as the other lines. The *spectrum resembles* that of *α Canum Venaticorum,* but the Europium lines are absent or very faint. Some of the lines are suspected to vary in intensity. These are identical with the so-called "second group" of variable lines in α Canum Venaticorum.

The *two components* of this system are believed to be *almost in contact.* The small width of the absorption lines is probably due to the fact that the planes of orbital motion and of axial rotation of the two stars coincide, and that their inclination is small.

The radial velocity of 36 τ^9 Eridani was found to be variable by E. B. Frost,[1] in 1907, when nine spectrograms were obtained with the Bruce spectrograph of the Yerkes Observatory. After that the observations of this star were discontinued. At the suggestion of Professor Frost a new series of observations was begun in December, 1924, and the material available at present is sufficient for a determination of the orbit.

The position of τ^9 Eridani, or Boss 923, for 1900 is: $\alpha\ 3^h15^m.7$, $\delta-24°18'$. Its visual magnitude is 4.69[2] and its color-index is zero. The spectral type is given in the *Henry Draper Catalogue* as Aop, and a remark calls attention to the unusual strength of the silicon lines 4128.1 and 4131.1 and of the strontium line 4077.9. A more detailed description of this spectrum is given in a later section of this paper.

The radial velocities.—In addition to 9 early plates taken in 1907–1908, we have utilized 41 spectrograms taken with the one-

[1] *Astronomische Nachrichten,* **177,** 174, 1908.

[2] *Henry Draper Catalogue,* No. 25267.

TABLE I

Radial Velocities of 36 τ^9 Eridani

Date G.C.T.	Observer	Quality	Velocity				Mean Velocity
			σ	σ	Hu	Hu	
1907 Feb. 16.040	F, Fox	g	+ 7.9	.....	+12.3	.....	+10.1
Dec. 20.153	F, L, S	f	+31.8	.....	.....	.....	+31.8
Dec. 30.167	Fox, S	g	−25.8	−27.1	−33.2	.....	−28.7
1908 Jan. 13.113	F, L, S	g	+50.1	.....	.....	.....	+50.1
Jan. 17.151	L, S	g	−17.3	−31.6	−29.2	.....	−26.0
Jan. 18.018	B, F, S	g	+11.3	.....	+ 3.8	.....	+ 7.5
Jan. 21.076	L, S	g	+37.9	.....	+30.6	.....	+34.2
Jan. 28.083	B, S	g	+ 5.2	.....	−11.6	.....	− 3.2
Feb. 3.054	B, S	g	+ 1.4	.....	+ 8.2	.....	+ 4.8
1924 Dec. 1.242	σ, S	f	+ 7.2	+ 3.1	+ 3.1	.....	+ 4.5
1925 Jan. 10.090	σ, S	g	− 5.2	− 7.4	− 4.3	.....	− 5.6
Jan. 31.038	σ	p	+55.6	+39.7	+45.7	.....	+47.0
Feb. 1.044	B	f	+61.0	+52.8	+48.1	.....	+53.9
Feb. 5.070	B, S	p	+ 3.7	+ 0.3	+19.8	.....	+ 7.9
Feb. 12.050	B, σ, S	g	+24.7	+23.9	+29.2	.....	+25.9
Nov. 2.350	B, S	g	+68.4	+67.0	+63.7	.....	+66.4
Nov. 14.292	σ, S	g	+58.3	+59.1	+51.6	.....	+56.3
1926 Jan. 10.131	σ, S	g	−11.4	− 9.5	−24.9	−15.9	−15.4
Sept. 15.490	σ	g	+33.9	+35.1	.....	.....	+34.5
Sept. 15.510	σ	g	+27.1	+25.8	.....	.....	+26.4
Sept. 16.471	σ	g	−13.9	−12.9	.....	.....	−13.4
Oct. 13.374	σ, M, S	f	+55.2	+64.9	+64.2	.....	+61.4
Oct. 13.408	σ, S	f	+60.8	+60.2	+53.7	.....	+58.2
Oct. 15.317	σ, S	g	+30.1	+29.5	+28.1	.....	+29.2
Oct. 15.353	σ, S	g	+41.5	+40.8	+36.3	.....	+39.5
Oct. 15.392	σ, S	g	+38.9	+33.6	+32.4	.....	+35.0
Oct. 21.317	σ, M, S	g	+32.7	+33.3	+30.4	.....	+32.1
Oct. 26.288	σ, M, S	g	+55.9	+61.0	+54.8	+61.3	+58.3
Oct. 26.324	σ, S	f	+62.6	+63.2	+49.8	+56.1	+56.4
Nov. 2.278	σ, S	g	+22.3	+22.2	+21.9	.....	+22.1
Nov. 2.312	σ, M	g	+18.3	+21.8	+22.8	.....	+21.0
Nov. 23.335	σ, S	f	+35.7	+30.7	+32.1	.....	+32.9
Nov. 27.277	σ, S	p	−18.3	−41.0	.....	.....	−29.5
Dec. 30.165	B, S	g	+56.6	+52.9	+48.4	+43.4	+50.2
1927 Jan. 6.102	B, S	g	+45.9	+52.0	+39.5	.....	+45.8
Jan. 7.077	σ, Hu, S	g	+14.3	+16.2	+14.6	.....	+15.0
Jan. 7.118	σ, Hu, S	g	+18.6	+17.5	+20.4	.....	+18.8
Jan. 7.159	σ, Hu, S	g	+11.6	+12.0	+11.1	.....	+11.6
Jan. 14.123	σ, S	g	−15.6	−10.8	−18.8	.....	−15.1
Jan. 14.167	σ, S	f	−22.8	−24.4	−28.3	.....	−25.2
Jan. 15.002	σ, M, S	g	− 0.4	+ 3.6	+ 6.7	.....	+ 3.3
Jan. 15.053	B, M, S	g	+ 6.2	+ 8.8	+ 6.7	.....	+ 7.2
Jan. 15.098	σ, M, S	g	+ 1.6	+ 7.8	+16.2	.....	+ 8.5
Jan. 15.138	σ, M, S	f	+ 9.0	+ 6.8	.....	.....	+ 7.9
Jan. 15.178	σ, M, S	p	+18.9	+18.6	+14.4	.....	+17.3
Jan. 20.015	B, σ, M	g	−16.8	.....	−14.2	.....	−15.5
Jan. 20.133	M, σ, S	f	−22.4	.....	−32.4	.....	−27.4
Jan. 27.104	B, M, S	g	+18.0	.....	+20.9	.....	+19.4
Jan. 27.144	B, M, S	g	+19.4	.....	+19.9	.....	+19.6
Feb. 1.088	σ, Hu, S	f	−12.0	.....	− 5.3	.....	− 8.6
Feb. 4.004	B, M, S	g	+55.2	.....	+56.8	.....	+56.0
Feb. 4.056	B, M	g	+57.7	.....	+54.0	.....	+55.8
Feb. 4.102	M, S	f	+59.3	.....	+62.5	.....	+60.9

The names of the observers and the quality of the plates are designated as follows: B = S. B. Barrett; F = E. B. Frost; Fox = Philip Fox; Hu = C. Hujer; L = O. J. Lee; M = W. W. Morgan; σ = O. Struve; S = F. R. Sullivan; g = good; f = fair; p = poor.

prism Bruce spectrograph during the years 1924–1927. Three additional spectrograms were secured by Struve with the 60-inch reflector of the Mount Wilson Observatory, on two consecutive nights in September, 1926. All 53 plates were measured by Struve, and most of them were independently remeasured by Hujer. Since the lines are sharp and well defined, the precision of setting should be greater than is usually the case for stars of early spectral types. This

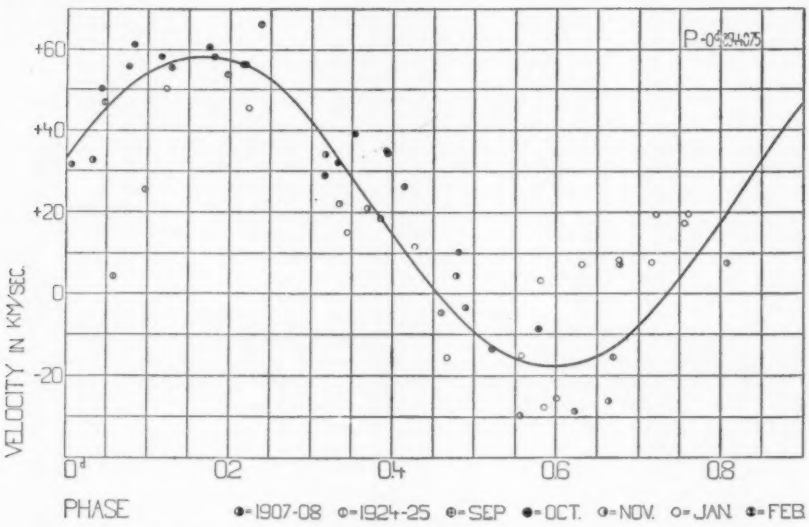

FIG. 1.—Velocity curve of 36 τ^9 Eridani. The observations were reduced with the average period 0.8544075 day. Velocities obtained in September, 1926, are shifted slightly to the right of the curve. Those of October and November, 1926, agree with the curve, while January and February are shifted to the left. Phase zero corresponds to J.D. 2424804.000. G.C.T.

is brought out by the individual results collected in column 4 of Table I. The lines used for determining the radial velocity were: *Ca*+3933.667, $H\delta$ 4101.738, *Si* +4128.053, *Si*+ 4130.884, $H\gamma$ 4340.467, *Mg*+ 4481.230, *Fe* 4549.474, and $H\beta$ 4861.326. Systematic corrections have been applied to all of the measures, and the results are believed to be free from any appreciable errors due to the instrument or to the method of reduction.

The period.—An inspection of the three Mount Wilson plates of September, 1926, showed that the period must be short. In fact, the

two plates of September 15, separated by an interval of only 30 minutes, clearly show the change in velocity. Later observations fixed the period at about 0.85 day. Long series of observations obtained during the same night show that the period cannot be very different from this value. After a number of attempts, it was found possible to combine all observations with a period of 0.8544075 day. Figure 1 shows the observations plotted against phase computed

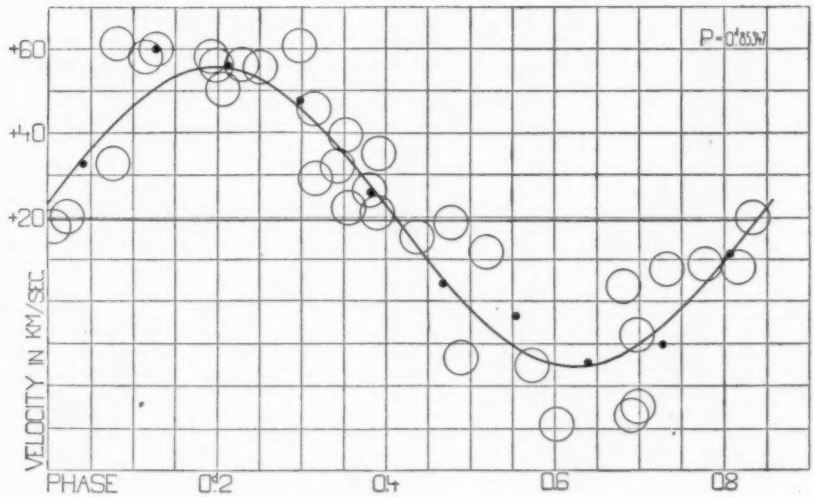

FIG. 2.—Velocity curve of 36 τ^9 Eridani used for orbit-determination. The open circles represent the individual observations. Their radii correspond to the probable errors. The black dots are normal points. Phase zero corresponds to J.D. 2424804.000 G.C.T.

with this value. Although, in general, the observations follow the smooth curve of the diagram, it will be seen that the residuals are very large, amounting in a few cases to as much as 40 km/sec. The good inner agreement of our measurements convinced us that errors of observation could not be responsible for such residuals. A closer inspection of Figure 1 discloses the real cause of the large deviations from the curve. It will be seen that the observations of January and February, 1927, are noticeably displaced toward the smaller phases, indicating that the adopted period is too long. It was found, accordingly, that the observations beginning in September, 1926, and ending in February, 1927, could best be represented by a period of

0.85347 day. The corresponding velocity curve is shown in Figure 2. With this period we have computed the phases for all preceding observations. Figure 3 shows a plot of the observations between December 1, 1924, and January 10, 1926. They fall into two distinct groups corresponding to the seasons 1924–1925 and 1925–1926. The first group is separated by about 735 revolutions from our principal epoch in October, 1926, or J.D. 2424804.000 G.C.T. For the second group the separation is 385 revolutions. It is obvious that the

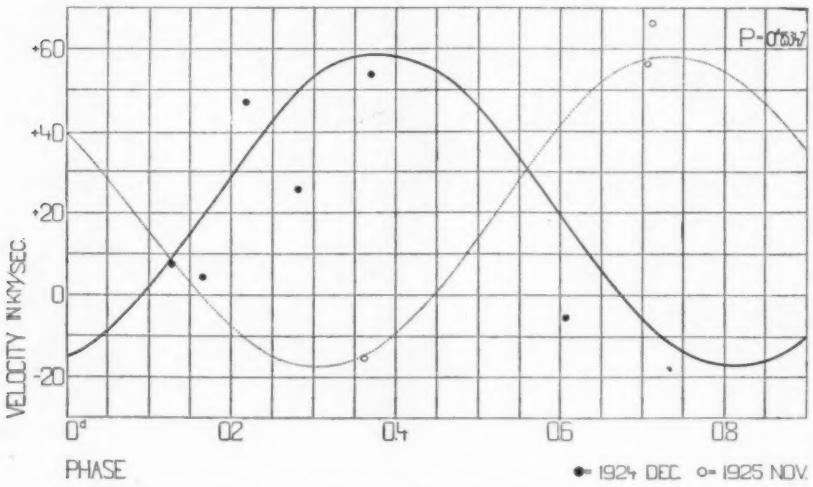

FIG. 3.—Radial velocities of 36 τ^9 Eridani, December, 1924—January, 1926, reduced with $P=0.85347$ day.

adopted period does not satisfy these observations. In order to bring them into agreement with the observations of 1926–1927, we have either to shorten the period by about 0.00143 day or to lengthen it by 0.00086 day. The first alternative leads to a period of 0.85204 day, which cannot be used to represent the observations of 1926–1927. Figure 4 illustrates this point. The second alternative brings us back to our original period of 0.8544 day which we discarded as being too long. It is, therefore, clear that the period is variable, and that the changes are sufficiently large to show from one season to the next. Tentatively, we may assume that our original value of 0.8544075 day represents the average period. If this is correct, a change of 0.00094 day, or 1.5 minutes, takes place in about two years or 430

revolutions. This would amount to a change of 0.2 second per revolution. The effect upon the phase amounts to at least 0.1 day, and perhaps even more. The observations are not sufficiently numerous to permit investigating these changes in greater detail.

A period of 20.5 hours is rather unusual for a binary of spectral type Ao. However, in this particular case, there is good evidence that the star is actually a double. It is not known to be a Cepheid variable, nor does it exhibit any of the spectral peculiarities of these

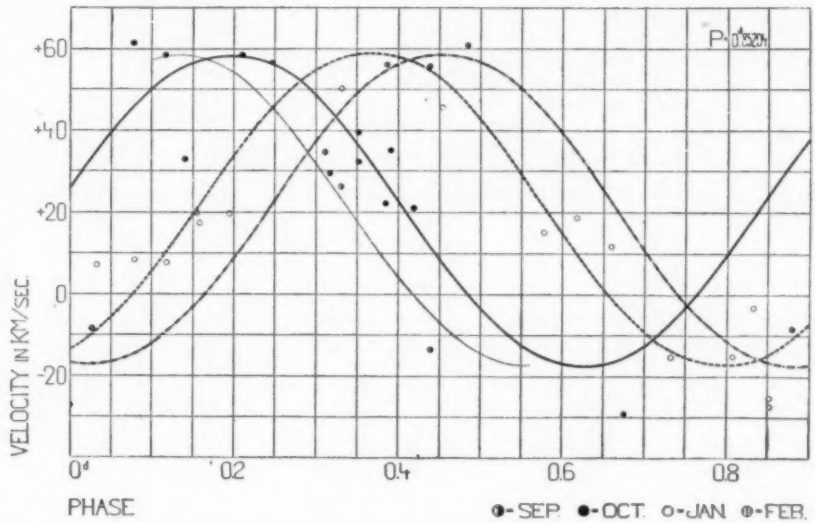

FIG. 4.—Radial velocities of 36 τ^9 Eridani, September, 1926—February, 1927, reduced with $P = 0.85204$ day.

stars. At maximum relative velocity faint lines due to the second component are just discernible and have been measured on several plates. As far as is known to us, the only other A-type star that is definitely known to be double, and that has a period shorter than one day, is S Antliae.[1] This star is, according to A. H. Joy, of spectral type A8 and has a period of only 15.5 hours.

The orbit.—In view of the observed changes in the period of τ^9 Eridani, we have considered it best to base the determination of the orbit exclusively upon the observations of 1926–1927, reduced with a period of 0.85347 day. A preliminary graphical determination of

[1] A. H. Joy, *Astrophysical Journal*, **64**, 287, 1926.

the elements was carried out according to the method of Lehmann-Filhés. Since the eccentricity was found to be less than 0.01, we have assumed the orbit to be circular and have carried through a least-squares solution for the velocity of the system, the principal epoch of maximum positive velocity, and the semi-amplitude of the variation in velocity. For this purpose we formed 10 normal points. The residuals δV were computed from the preliminary elements for each individual observation. The normal velocity for each interval of 0.0854 day was then computed in the following way:

$$\text{Normal velocity} = \text{Computed velocity} + \frac{\Sigma \delta V}{n} .$$

This method takes care of the curvature of the velocity curve, and the small number of normal points is not objectionable. The

TABLE II

NORMAL VELOCITIES

No.	Phase	No. of Plates	Velocity	$(O-C)_1$	$(O-C)_2$
1.....	0.0426	4	+32.7	−3.6	−1.5
2.....	.1279	1	+60.0	+8.0	+9.4
3.....	.2132	5	+55.9	+0.3	+0.7
4.....	.2985	3	+47.6	+1.8	+1.4
5.....	.3838	7	+25.9	−0.3	−1.3
6.....	.4691	3	+ 4.2	−0.2	−1.0
7.....	.5544	2	− 3.7	+7.6	+7.5
8.....	.6397	3	−15.1	−0.1	+0.7
9.....	.7250	4	−10.1	−4.9	−3.2
10.....	0.8103	3	+12.1	−2.2	−0.1

normal velocities were weighted according to the number of observations included. They are shown in Table II, together with their residuals. In Figure 2 they are represented by small dots. The adjustment by the method of least squares considerably improved the elements, as shown by the value of $[pv^2]$ which was reduced from 51.2 to 35.3. Table III shows the elements and their probable errors.

The epoch T in the circular orbit denotes the time of maximum positive velocity. The phases are counted from J.D. 2424804.000 G.C.T. The probable error of one normal velocity of weight unity

is ±1.5 km/sec. The probable error of one individual observation is ±4.0 km/sec.

The secondary component.—The best plates show at maximum relative velocity faint lines belonging to the second component. These were measured on seven plates for the determination of mass-ratio. The resulting velocities are given in Table IV. They are based

TABLE III

ORBITAL ELEMENTS

	Elliptical Graphic	Preliminary Circular	Corrections	Final	Probable Errors
γ	+20.5 km/sec.	+20.5	−0.8	+19.7	±1.1
P	$0^d.85347$	$0^d.85347$	Assumed	$0^d.85347$	.....
e	0.007	0.000	Assumed	0.000	.....
K	38.0 km/sec.	38.0	−2.3	35.7	±1.1
ω	90°	0°	Assumed	.....	.....
T	$0^d.406$	$0^d.193$	$+0^d.006$	$0^d.199$	$0^d.0032$
$a \sin i$	.....	.....	.....	419,000 km	.....
$m_1 \sin^3 i$	.....	.....	.....	$0.17\odot$	.....
$m_2 \sin^3 i$	.....	.....	.....	$0.06\odot$	.....

TABLE IV

MASS-RATIO

Date	V_1	V_2	m_2/m_1
1925 Nov. 2.350	+70.7	− 80.3	0.50
1926 Oct. 13.408	+68.7	−105.7	.39
1927 Jan. 14.123	−23.1	+197.9	.24
1927 Jan. 20.015	−20.4	+142.6	.31
1927 Feb. 4.004	+58.9	−121.7	.28
1927 Feb. 4.102	+60.0	− 92.8	0.36
Mean.....	.....	.....	0.35

only on the magnesium line 4481. The mass-ratio in the last column is the ratio V1/V2, corrected for the velocity of the system.

It was estimated that the magnesium lines of the second component are about 0.15 magnitude fainter than the background of the continuous spectrum. For the brighter component this value is about 0.6 magnitude. The two spectra seem to be similar in type.

The silicon lines.—In view of the extraordinary strength of the lines of ionized silicon in the spectrum of τ^9 Eridani, we have examined, separately, the radial velocities obtained from them. B. P.

Gerasimovič[1] has pointed out the importance of these lines and has suggested to us that it would be desirable to find whether this abnormal intensity is caused by a blending of a normal line with one of interstellar origin. The strontium lines 4078 and 4215 would be even more interesting; but contrary to the remark in the *Draper Catalogue*,[2] they appear extremely faint on all of our plates, and are measurable only with difficulty. The line 4078 is, furthermore, complicated by the existence of a line at 4076 the origin of which is doubtful.

The silicon lines 4128 and 4132, however, give very reliable results, and the velocities derived from them agree with those from the magnesium line 4481 and from the iron line 4550. A velocity curve was constructed separately for the silicon lines, and it was found to agree in phase and in amplitude with the curve from other spectral lines. The average difference between the silicon and the magnesium velocities is smaller than the probable errors of the measurements. This proves that if an effect of blending is present at all, the interstellar line must be very faint and cannot account for the great intensity of the observed line. It seems decidedly probable that the silicon lines originate in the atmosphere of the star.

The evidence concerning the strontium lines is less conclusive. They were measured on several plates for determination of wavelength, and the results seem also to indicate that they behave normally with respect to velocity.

The spectrum.—The general appearance of the spectrum of τ^9 Eridani greatly resembles that of α Canum Venaticorum. We have examined plates of both stars under the Hartmann spectrocomparator and have found that the calcium line 3933, the hydrogen lines, and the lines of ionized silicon are of nearly the same intensity in both stars. Belopolsky's[3] and Kiess's[4] second group of variable lines are also represented in τ^9 Eridani. But the first group, assigned by Baxandall[5] and by Kiess[4] to Europium, is very faint or absent in τ^9 Eridani. Table V gives a list of all such lines as could be measured

[1] *Astronomische Nachrichten*, **228**, 427, 1926.

[2] *Annals of the Harvard College Observatory*, **91**, 290, No. 25267, 1918.

[3] *Astronomische Nachrichten*, **196**, 1, 1913.

[4] *Publications of the Astronomical Observatory, University of Michigan*, **3**, 106, 1919.

[5] *Monthly Notices of the Royal Astronomical Society*, **74**, 32, 1913.

TABLE V

WAVE-LENGTHS OF ABSORPTION LINES IN 36 τ^9 ERIDANI

Wave-Length I.A.	Intensity	Identification
3930.43	1	*Eu* 3930.51?
3933.68	3	*Ca+* 3933.67
3954.40 *v*	2	*Tb* 3954.06?
3967.89	2	*Ca+* 3968.48
3970.07	50	*H*ϵ 3970.08
3991.95	1	.....
4002.83 *v*	1	*Tb* 4002.58?
4012.76	1	*Tb* 4012.84? *Ti+* 4012.39*
4025.52	1	*Ti+* 4025.14*
4045.88	1	*Fe* 4045.82
4049.37 *v*	3	.....
4057.50 *v*	1	.....
4070.76	1	.....
4075.77	1	.....
4077.37	2	*Sr+* 4077.74
4102.01	50	*H*δ 4101.74
4122.93	2	*Fe+* 4122.67*
4128.31	10	*Si+* 4128.05
4131.07	10	*Si+* 4130.88
4143.83	1	.....
4151.58 *v*	1	.....
4179.02	1	*Fe+* 4178.87
4187.75 *v*	1	.....
4190.99 *v*	2	.....
4200.96 *v*	4	*Tb* 4201.00?
4203.46	1	.....
4215.82	1	*Sr+* 4215.52
4233.81	4	*Fe+* 4233.17
4242.76	1	*Tb* 4242.58? *Cr+*4242.38*
4263.03	1	.....
4267.24	1	*C* 4267.22?
4278.48 *v*	1	.....
4284.72 *v*	1	.....
4325.75	2	*Fe* 4325.77
4340.37	50	*H*γ 4340.47
4342.10	1	*Tb* 4342.54?
4349.02 *v*	1	.....
4351.79	2	*Fe+* 4351.76*
4353.01	1	.....
4371.96	1	.....
4373.22 *v*	1	.....
4377.44	2	.....
4384.57	1	*Fe* 4385.38*
4394.67	1	*Ti+* 4395.04
4430.58 *v*	1	.....
4434.21 *v*	1	.....
4472.19	1	.....
4481.24	9	*Mg+* 4481.23
4508.42	1	*Fe+* 4508.27
4515.51	1	*Fe+* 4515.34*
4534.37	1	*Ti+* 4533.98 *Fe+* 4534.17*
4549.46	5	*Fe+* 4549.47 *Ti+* 4549.64*
4555.81	1	*Fe* 4555.92*

TABLE V—*Continued*

Wave-Length I.A.	Intensity	Identification
4559.58	1	*Cr*+ 4558.64
4564.00	1	*Ti*+ 4563.76
4572.08	1	*Ti*+ 4571.98
4583.82	2	*Fe*+ 4583.83
4588.65	1	*Cr*+ 4588.20*
4621.72	2	.....
4813.60	1	.....
4861.34	40	*Hβ* 4861.33

on our one-prism plates. The spectrograms were compared with one another in the spectrocomparator, and only such lines were measured as could be seen on several plates.

In the early stages of this work it was noticed that some of the fainter lines, chiefly the ones at λ 4123 and λ 4472, were occasionally fairly strong, while at other times they could not be seen on some of the best plates. This led us to the suspicion that the two lines in question were variable in intensity. At first it was believed that they were due to helium, and indeed the same assumption had been made by the Harvard observers.[1] The wave-lengths in Table V show, however, that they are not identical with the helium lines, and it is reasonable to assume that they are the same lines which occur in the spectrum of α Canum Venaticorum. The line at λ 4123 was found to be variable by Belopolsky and confirmed as such by Kiess. The probable variability in the intensity of λ 4472 was first pointed out by H. Ludendorff.[2] In view of the variability of these lines in α Canum Venaticorum, and also because of the suspected changes in intensity in τ^9 Eridani, we have estimated the intensity of a selected number of lines on most of our newer plates. The results, expressed on an arbitrary scale, are given in Table VI. Complete absence of a line was denoted by 0. A line that was only suspected was called "1"; "2" was used to denote a very faint, but undoubtedly real line; while a line visible at the first glance was called "3"; "4" and "5" denote strong lines. In Table VII the estimates are arranged in groups of 0.1 day in phase. There seems to be a drop in intensity for all lines listed around phase 0.4 day to 0.5 day, and a maximum at or

[1] *Annals of the Harvard College Observatory*, **28**, 186, Remark 144, 1897.

[2] *Astronomische Nachrichten*, **173**, 5, 1906.

TABLE VI

INTENSITIES OF LINES IN τ^9 ERIDANI

DATE	LINE				
	4123	4201	4233	4325	4472
1924 Dec. 1.242	.....	.....	.....	.....	3
1925 Jan. 10.090	1	3	3	2	1
1925 Feb. 12.050	0	2	1	0	1
1925 Nov. 2.350	0	1	2	3	3
1925 Nov. 14.292	1	3	3	0	0
1926 Jan. 10.131	0	4	3	0	0
1926 Oct. 13.408	.....	2	3	3	3
1926 Oct. 15.317	1	2	2	1	1
1926 Oct. 15.393	1	1	3	1	1
1926 Oct. 15.352	1	1	2	1	2
1926 Oct. 21.317	1	1	2	2	3
1926 Oct. 26.288	4	0	0	4	2
1926 Oct. 26.324	1	3	3	3	3
1926 Nov. 2.278	0	0	1	1	0
1926 Nov. 2.312	1	1	1	1	0
1926 Dec. 30.165	1	4	3	2	2
1927 Jan. 6.102	0	1	3	0	1
1927 Jan. 7.077	2	2	2	1	1
1927 Jan. 7.118	0	2	2	2	1
1927 Jan. 7.159	0	2	2	1	2
1927 Jan. 14.123	1	3	3	4	4
1927 Jan. 14.167	3	2	4	4	4
1927 Jan. 15.002	3	3	3	2	2
1927 Jan. 15.053	3	3	4	3	2
1927 Jan. 15.098	3	2	5	2	1
1927 Jan. 15.138	2	4	4	2	2
1927 Jan. 20.015	0	3	1	1	0
1927 Jan. 20.133	1	2	3	0	.....
1927 Jan. 27.104	2	1	4	2	0
1927 Jan. 27.144	1	2	1	1	0
1927 Feb. 4.004	1	3	2	1	1
1927 Feb. 4.056	2	4	3	1	2

TABLE VII

INTENSITIES OF LINES GROUPED ACCORDING TO PHASE

PHASE IN DAYS	LINE				
	4123	4201	4233	4325	4472
0.1.....	2.3	2.0	2.0	2.5	1.8
.2.....	1.2	3.5	2.8	1.8	2.0
.3.....	0.5	1.0	2.0	2.0	1.4
.4.....	1.0	1.2	2.0	1.0	1.0
.5.....	0.5	2.5	1.9	1.2	0.6
.6.....	1.7	2.7	3.0	2.2	3.0
0.7.....	2.8	2.0	4.2	2.8	1.9

near phase 0.7 day. However, this result must be regarded as uncertain since the number of plates was so small that accidental distribution of the observations may easily result in an effect as shown in Table VII. The total amplitude of intensity is not large. Thus the line λ 4123 reaches an intensity equal to about one-half of the silicon line 4128 on only one plate; on other equally good plates it is entirely absent. For the other lines the variation is even smaller. We feel that the question of the variability of the lines in τ^9 Eridani is not completely established, although there remains a strong suggestion that it is real.

As to the identification of the lines in Table V we have in general followed the identifications made by Kiess for α Canum Venaticorum. The identification by Kiess of some of the lines with terbium seems possible although by no means certain. The fairly strong line λ 4233 is evidently chiefly due to ionized iron, and not to terbium. Again, some of the stronger terbium lines listed by Kayser[1] do not occur in τ^9 Eridani, nor do they occur in the list of lines of α Canum Venaticorum given by Kiess.[2] Probably many of the fainter lines in τ^9 Eridani are enhanced metallic lines.

Mr. F. E. Baxandall has had the kindness to read our paper before publication and has suggested a number of additional or alternative identifications. These are shown by asterisks in the last column of Table V. Mr. Baxandall also remarks that some of the lines in τ^9 Eridani are probably identical with lines in the spectrum of 46 υ Sagittarii, as observed by J. S. Plaskett. Mr. Baxandall's identifications were made on a paper print of the spectrum of this star prepared at Victoria. We have noted these lines in the first column of Table V by the letter υ.

General conclusions.—τ^9 Eridani is not known as an eclipsing variable, and we have no definite information concerning the actual dimensions of the system. Nevertheless it is possible to make certain plausible suppositions and to gain an insight into the structure of this double star. We have estimated that the intensity difference between the continuous spectrum and the lines of the two components is 0.6 magnitude for the brighter and 0.15 magnitude for

[1] H. Kayser, *Handbuch der Spectroscopie*, **6**, 595, 1912.

[2] *Publications of the Astronomical Observatory, University of Michigan*, **3**, 113, 1919.

the fainter component. These values do not directly indicate the respective brightnesses of the two stars. The continuous background is formed by the light of both stars, while the lines of the brighter component are superposed upon the continuous spectrum of the fainter, and vice versa. Previous experiments of superposition of spectra of different stars indicate that a difference in observed line-intensity, as given above, corresponds to a difference in brightness between the two components of about 0.5 magnitude. Since the total visual magnitude of τ^9 Eridani is 4.7, the magnitudes of the components would be 5.2 and 5.7 respectively.

The parallax of τ^9 Eridani has not been determined by the trigonometric methods. But its absolute magnitude was estimated by Miss A. V. Douglas[1] as +0.5, making the absolute parallax about 0.012. The corresponding absolute magnitudes of the components would be +1.0 and +1.5 respectively. Knowing the absolute magnitudes and adopting for both components the spectral type A1s, as given by Miss Douglas, we estimate by the method of Russell[2] that the linear diameters of the components are 2.9 and 1.8 times that of the sun. The masses are not known, since the inclination remains undetermined. We may assume, however, with a reasonable degree of certainty that the total mass of the system is twice that of the sun.[3] This value is probably rather underestimated, but it conforms with our general knowledge of masses of A-type spectroscopic binaries. If these data are correct, a period of 20.5 hours must correspond to a distance of 3,200,000 km between the centers of the two stars. But the first star has a radius of about 2,030,000 km, while that of the second is 1,260,000 km. The sum of these radii is nearly identical with the distance of their centers. The stars are, therefore, in contact, or, making allowance for possible errors in our estimated values, they must be very close to one another.

One feels inclined to attribute the observed changes in the period to this proximity of the surfaces of the two components and to the effect of tidal disturbances. However, it seems very strange that a star so similar to τ^9 Eridani, in period as well as in dimensions, as

[1] *Journal of the Royal Astronomical Society of Canada*, **20**, 285, 1926.

[2] *Publications of the Astronomical Society of the Pacific*, **32**, 307, 1920.

[3] O. Struve, *Monthly Notices of the Royal Astronomical Society*, **86**, 67, 1925.

S Antliae, does not exhibit any variations in the period.[1] Even more surprising is the difference in the general appearance of the spectral lines of these two stars. In S Antliae the lines are, according to Joy, "wide and hazy, because of a large rotational effect like that found in W Ursae Majoris." In τ^9 Eridani the lines are narrow and sharp, although the velocity of axial rotation must be even greater than in S Antliae. It seems to us that this difference in the widths of the lines is a strong observational argument in favor of the hypothesis that the planes of axial rotation and orbital motion coincide in such close binaries. The evidence available from S Antliae and τ^9 Eridani is, of course, only of a qualitative nature, since the actual width of the lines in S Antliae is not mentioned in Joy's paper and since the line-width in τ^9 Eridani is close to the limit imposed by the construction of the spectrograph. However, as far as can be judged from Joy's description, the values agree well with the hypothesis.

In view of the additional information that can be gained from the observation of eclipses, it would seem desirable to test τ^9 Eridani for variability in light. Unfortunately, the comparatively small value of K points to a small inclination. Continuing our deductions made from the above estimates of mass and diameter, we would expect the inclination to be of the order of only 10°.

YERKES OBSERVATORY
March 1, 1927

[1] *Astrophysical Journal*, **64**, 287, 1926.

INFLUENCE OF ATMOSPHERIC CONDITIONS ON THE EFFECTIVE WAVE-LENGTHS OF STARS

By RICHARD A. ROBB

ABSTRACT

By comparing the observed with the computed value of the "constant" of the objective grating, we *can allow for* the effect of the *state of the atmosphere on effective wave-lengths*. The scale-unit employed was that used by Parkhurst in his determination of the photometric magnitudes of the stars in the Kapteyn zone +45°.

The important influence that the atmosphere has on the effective wave-lengths ($\lambda_{\text{eff.}}$) has been found by various observers. In the paper by Lundmark and Luyten on "The Color Equivalents of Stars,"[1] it is stated that Vallin and Lundmark found a fogging effect at Upsala. A mean difference of 30 A was obtained between nights when there were a foggy sky and high humidity, compared with nights when the sky was clear and humidity low. Davidson and Martin in two papers[2] have noticed the same effect, and ascribe it to various causes as, for example, fog, smoke, etc. They did not find, however, any quantity that would act as a measure to systematically correct wave-lengths obtained from plates taken on different nights. A suitable quantity seemed to be the scale-unit so extensively used by the late J. A. Parkhurst. This unit is defined below. By correlating the scale-unit with the wave-lengths, a progressive variation was obtained, thus enabling one to allow for changes in the atmosphere.

The "constant" of an objective grating is defined as the difference in magnitude between the central and spectral images, and is directly proportional to the ratio between the aperture and the sum of aperture and opaque regions.[3] It can thus be obtained theoretically and its value checked by exposures on stars of known magnitude. Owing to various conditions of seeing, the constant obtained from observation fluctuates considerably, and Parkhurst accordingly mul-

[1] *Monthly Notices*, **82**, 495, 1922.

[2] *Ibid.*, p. 68, 1921; *ibid.*, **84**, 425, 1924.

[3] *Popular Astronomy*, **28**, 326, 458, 1920.

tiplied his artificial scale readings, to convert them into a system of magnitudes which only require further correction for zero point to obtain absolute values, by the ratio of the theoretical value of the constant to the observed value for any one plate. As an example, let the theoretical constant of a grating be 2.80 mag., and on one night, say, the observed value, i.e., the difference between the magnitudes of the central and spectral images is 4.20 mag. The scale readings are then multiplied through by 2.80/4.20 or by 0.571. It is this ratio (S) that I have used as a measure of "seeing," which is a function of transparence, definition, and the steadiness of the image. Dr. Alice Farnsworth[1] remarks on the variation of this quantity, stating that the value is systematically larger when conditions are unusually fine, and smaller when plates are taken under poor conditions of seeing.

The grating most frequently used by Parkhurst with the 24-inch reflector, reduced to an aperture of 12 inches, was the P7b, a partial normal grating, for which full particulars are given on page 24 of Dr. Farnsworth's paper. The grating was designed to give round images and a stronger central image than the normal grating. The spectral distance is consequently small and the "constant" large, so that such a grating would not give as accurate results as a grating having more rods. With the large number of plates available, however, the probable error is kept small.

The polar plates of Parkhurst taken at various periods from 1920 to 1924 gave the necessary material, and those for which the foregoing ratio was available numbered about fifty. The quality was in all cases "good." I had the opportunity of utilizing this material during the autumn quarter of 1926 which I spent at the Yerkes Observatory. Two stars of the Harvard Polar Sequence, Nos. 5 and 8, were selected. This was done because there were several exposures on each plate and it was possible to obtain 450 exposures for these two stars alone.

In measuring on a Gaertner astrometric comparator, three settings were made on each spectral image, the plate was then rotated through 180° and further sets of three were taken. On the central image two settings were made as the diameter was only required to 0.01 mm.

[1] *Publications of the Yerkes Observatory*, **4**, Part 5, 26, 1926.

Before proceeding with numerical results, it should be noted that the "spectral distance" (D) is given by the formula

$$D=\frac{2f\lambda_{eff.}}{a+d};$$

where $\lambda_{eff.}$ equals effective wave-length of star; f, focal length of lens; $a+d$, grating space; and D, distance between spectral images. In all that follows, D is used instead of $\lambda_{eff.}$, as the factor $2f/a+d$ is a constant for the given telescope and grating.

Normal intensity of the central image is assumed to correspond to a diameter of 0.10 mm, and corrections are necessary for diameters varying from normal. These have been taken from Professor Hertzsprung's study of the Pleiades,[1] but divided by four, as his grating gave spectral distances very nearly four times as large as those of the P7b. In unpublished work at the Yerkes Observatory, Dr. H. L. Vanderlinden has obtained similar results. The corrections are:

d*	Cor. to D
0.06	+0.003
.07	.002
.08	.001
.09	.0005
.10	.0000
.11	− .0005
.12	.001
.13	.001
.14	.001
0.15	−0.002

* d is diameter of central image in mm.

To verify these results, plates taken on two nights giving the largest number of exposures with the least change of scale-unit (S) were examined. These two plates gave definite results for diameters 0.09 and 0.11 mm from a series of 25 exposures of H.P.S. 5.

d	D	Scale-Unit (S)
0.09	0.25470	.906
0.11	0.2560	.867

The correction is slightly larger but I have preferred to take Professor Hertzsprung's table.

[1] *Astrophysical Journal*, **55**, 371, 1922.

The length D is therefore a function of two variables, the diameter d of the central image and the scale-unit S. In the first place, each plate was considered individually. The average diameter d and the average distance D were obtained for a corresponding scale-unit S. The plates were then grouped according to scale-unit, and in the table below the limits are given, together with the mean value for the group:

S*	d	D	No. of Exposures
0.495–0.595 } 0.57	0.12	0.2538±0.00033	41
.595– .695 } .64	.12	.2545± .00024	75
.695– .795 } .74	.10	.2544± .00019	100
0.795–Onward } 0.85	0.10	0.2557±0.00017	94

* H.P.S. 5.

The same grouping was also tried, only values of $d=0.09$, 0.10, 0.11 being used. The results were:

S	d	D	No. of Exposures
0.58	0.10	0.2534	16
.64	.10	.2534	26
.74	.10	.2544	62
0.85	0.10	0.2549	70

An examination of these two tables discloses the following results: (1) D constant equals 0.2544; a change of +0.10 in S corresponds to a change in d of +0.02 mm. (2) d constant equals: (*a*) $d=+0.12$ mm; a change of +0.07 in S corresponds to a change in D of +0.0007; (*b*) $d=+0.10$. A change of +0.11 in S corresponds to a change in D of +0.0013. This change is seen in the last three lines of the second table, although the last line gives a smaller result. (3) S constant equals 0.64. A change of +0.02 in d increases D by +0.0011 which corresponds to the proposed corrections given earlier, with the following result:

*S**	*D*
0.57	0.2528
.64	.2535
.74	.2544
0.85	0.2557

* H.P.S. 5.

As a change of .001 in D corresponds to a change of 17 A in $\lambda_{eff.}$, the effect is considerable, a variation in S of 0.2 giving a difference of 34 A.

For star H.P.S. 8 we have the following results (the grouping of S being as before):

S	*d*	*D*	No. of Exposures
0.66	0.12	0.2555	42
.75	.09	.2544	22
0.82	0.11	0.2561	10

Correcting for d we get:

S	*D*
0.66	0.2545
.75	.2549
0.82	0.2555

We see, therefore, that both stars show the same characteristics with regard to the unit employed to measure conditions of seeing, and that for H.P.S. 5 a difference of 0.10 in S gives a significant difference to D. Davidson and Martin[1] put the probable error of a single night at ± 17 A. From the distribution of the values of S, the mean error is found to be ± 0.10 corresponding to ± 17 A, and hence in one night out of three it is to be expected that the effective wave-length will vary from its mean value by this amount. In one night out of twenty-one there is a possibility that the deviation will be as much as ± 34 A. This taken into account with the plate error of ± 10 A found by Hertzsprung[2] shows to what extent systematic errors may enter into the method of effective wave-lengths. Here the magnitudes of the images of the stars have been measured by intensity

[1] *Monthly Notices*, **82**, 65, 1921.

[2] *Astrophysical Journal*, **42**, 92, 1915.

methods, and it is doubtful if the same results would be obtained by direct measurement of their diameters. It should be noted (1) that the foregoing results will vary according to the grating used; and (2) that if polar plates be taken on the same nights as plates of other regions, there will be in general no need of finding S, though the seeing is known to vary considerably even during one night.

YERKES OBSERVATORY
June 1927

REVIEWS

Linienspektren und periodisches System der Elemente. By FRIEDRICH HUND. Vol. IV of the series, "Structur der Materie in Einzeldarstellungen," edited by M. BORN and J. FRANCK. Berlin: Julius Springer, 1927. Pp. vi+221. 43 figs. M. 16.20.

In this monograph are collected the results of the most recent advances in the interpretation and analysis of line spectra on the basis of the quantum theory—results to which the contributions of Dr. Hund himself have been considerable. It should prove of almost equal interest to the spectroscopist and to the student of theoretical physics, for it treats of both the present status of the term-analysis of individual spectra and the meaning of the empirical results for atomic dynamics.

The treatment of the theory is concise, but clear, and dominated throughout by the correspondence principle. No great familiarity with higher analysis is required. The author's statement in the Preface that the theory of line spectra in its essential features has reached a certain state of internal completeness seems at first sight strange at a time of changing physical theories like the present. Apparently this is to be understood in the sense that however unsatisfactory the original formulation of the Bohr theory may be as a logical basis for a theory of atomic dynamics, it may nevertheless, with remarkably little modification in its fundamental ideas, still be used as an internally consistent scheme for the interpretation of a vast amount of spectral data. The book itself is a justification of this statement, for the qualitative and semi-quantitative features of even the most complicated spectra are accounted for and predicted on the basis of Bohr's two postulates, the correspondence principle and the adiabatic principle, augmented by Pauli's rule for equivalent orbits and applied to the usual model with addition of the spin of the electron and its double magnetism. The meaning of the Heisenberg and Schrödinger quantum mechanics is discussed and the viewpoint is that these fundamental reformulations become absolutely essential only for quantitative calculations of a kind not attempted in this book. Thus the study of spectra and their relation to the periodic system is not closed to those unfamiliar with higher algebra and the theory of differential equations. Of particular interest is the careful definition of the meaning of the

term atomic "model." It enables us to use the word with a more comfortable feeling.

Many tables of the theoretically predicted terms and their multiplicity are here published for the first time. X-ray spectra are briefly discussed, but band spectra are left to another volume of this series.

FRANK C. HOYT

Proceedings of the Optical Convention 1926. Aberdeen: University Press, 1926, 2 vols. 4to. Part I, pp. x+512; Part II, pp. viii +578. Pls. 51; figs. 392. £3 net.

These two handsome volumes contain the full text of the scientific papers—nearly a hundred in number—and the presidential address read at the Optical Convention held at the Imperial College of Science and Technology, South Kensington, London, April 12–17, 1926. The work constitutes an excellent record of the outstanding progress in optical science and technology, and especially in applied optics, made by the British since the Convention of 1912. Numerous phases of optics and optical instrument manufacture and use are dealt with. And while a few of the papers are practically repetitions of ones that have appeared in print during the past few years, all represent advances and improvements and many are of exceptional merit in their subject matter. None could have been left out without detracting from the value of the work for reference purposes.

Not only are matters in the theory, design, manufacture, and use of optical devices of many kinds treated, but color and color vision, photometry and illumination, physiological optics and ophthalmology, astronomy, geodesy, photography and cinematography, surveying and navigation, and various other matters are given a good share of attention. The subject matter ranges from the microscope to the lighthouse; from the problems of geometrical optics, as applied to optical designing, to a consideration of certain possibilities of relativity and quantum theories.

Being made up of so many papers on such a variety of subjects it is obvious that the work can hardly be adequately reviewed in a few paragraphs—the titles alone would fill several pages. But in this record of fourteen years' progress in British optics certain features are noteworthy.

First of all, one may mention the advances made by the British in the manufacture of optical glasses—the remarkable improvements in quality and transparency, especially in such glasses as the barium crowns, and the doubling of the number of available types of glass. Disks of excellent barium crown almost free from color and large enough for medium-sized

astronomical telescopes were shown at the Convention. The designer now has greater freedom in the choice of glass combinations, and therefore has a better chance of finding pairs that best serve his purposes. Moreover, as a result of these advances in glass production, the light-passing power of lenses having a suitable field for stellar photography has been materially increased—practically doubled in some cases—without any increase in the clear aperture of the objective. Improvements of this kind may be expected to expedite the work of stellar photography in no small measure.

Turning to another subject, that of color and its measurement, there seems to have been a desirable increase in the number of investigators working on the more fundamental aspects of the problems involved. In Part I there is a very excellent critical survey of modern developments in the theory and technique of colorimetry.

Or again, one cannot fail to note the trend toward the installation of elaborate means for precise testing of the performance of optical parts. We find accounts of improved testing goniometers and spectrometers of large dimensions and high precision. But perhaps more interesting are the devices—sometimes quite complicated mechanically—for the testing of almost all kinds of optical parts by means of interference methods. The use of such testing methods must inevitably lead to a higher general standard of optical excellence, and especially to well-nigh perfect optical performance in certain kinds of apparatus for research use.

A delightful group of papers is that dealing with historical matters. There is an account of the old historical instruments exhibited at the Convention, an old catalogue of scientific apparatus collected by George III, descriptions and illustrations of telescopes made by Christopher Cock about 1673, and other early optical and scientific instruments now useful as documents of historical value.

The quality and variety of material to be found in this last addition to the proceedings of British optical conventions probably excels that of former volumes, while the volume is fully double that presented at any former meeting. The record is full of information for the worker in any branch of optical science and deserves careful reading and study.

G. W. MOFFITT

Traité de Physique. By O. D. CHWOLSON. Tome supplémentaire. *La Physique de 1914 à 1926.* Première partie. Traduite du russe par A. CORVISY. Paris: Librairie Scientifique J. Hermann, 1927. 8vo. Pp. 340. Figs. 54. Unbound, Fr. 63.

This first part of the supplementary volume brings the revised edition of the monumental treatise up to 1924. Neither the translator nor the

publisher cared to insert a prefatory note between the title-page and the beginning of the text on page 1. The translator added, in 1926, a few footnotes, in order to correct statements made by Chwolson in 1925, when the original text was written. The nine bibliographical lists attached to the nine chapters of the book consider the literature up to and including 1924.

In order to make the contents of the supplementary volume correspond to its title, *Physics from 1914 to 1926*, the coming second part will have to be, primarily, a supplement to the present first part, and but indirectly a continuation of the fundamental treatise.

Charge and mass of the electron are the subject of the first chapter. Millikan's experiments form the nucleus of the discussion.

The quantum theory is treated concisely and clearly on the two dozen pages of the next chapter, but not in an elementary way. The mathematical equipment of the reader of the preceding volumes of the treatise is sufficient as well as necessary for the study of this introduction to modern physics. Light-quanta will be the subject of a special chapter in the second part of the supplementary volume and are referred to here on but three pages.

The structure of the simple and of the polyelectronic atoms is discussed in the following two chapters. The treatment follows the chronological order of development of the subject. The space devoted to earlier conceptions may seem to be somewhat excessive, but it is deftly used in preparing a suitable background for the presentation of more recent ideas on the structure of atoms.

Line spectra are studied on the fifty pages of chapter v. The influence of the fourth (1924) edition of Sommerfeld's *Atombau und Spektrallinien*, unavoidable in the presentation of the subject matter of the two preceding chapters, has its counterpart in the relation of the third (1922) edition of that standard work to chapter v of this book. The essential points of the correspondence and selection principles are presented as clearly as can be done on fifteen pages with a modicum of mathematics. The Zeeman and the Stark effects are not treated in this first part of the supplementary volume.

The next chapter is on X-rays. In spite of the space, sixty-eight pages, allotted to new developments during the ten years covered by the book, only points of contact with the structure of the atom have been closely examined. The revised edition of Volume V of the treatise will take up such questions as absorption and diffusion, reflection and refraction of X-rays, or their use in the study of the structure of matter. A critical synopsis of the confusing designations of energy levels is given—not an attempt to standardize.

Band spectra form the subject of chapter vii.

The next chapter gives a short account of ultra-violet and infra-red radiations. Millikan's work of 1919–1921 is discussed on three pages. The last section of the chapter, on the passage from infra-red radiation to short electric waves, sums up, incidentally, the less well-known or otherwise inaccessible publications of Russian research workers.

The last of the nine chapters of the book, on excitation and ionization of gases by electronic impact, gives a good general view of the history of the question and of the results obtained.

Indices according to subject and author would greatly facilitate the use of the material brought and put together with so much care and discernment. The translator or the publisher should not omit such indices at the end of the completed supplementary volume.

Some of the figures in the text could be better. Cuts made from original drawings—not from poor reproductions—would not have been much more expensive.

Careful proofreading would have considerably reduced the number of misprints. Fortunately, most of them occur in the text, not in the formulae, and are easily noticeable.

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Edited by

GEORGE E. HALE
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EDWIN B. FROST
Yerkes Observatory of the University of Chicago

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